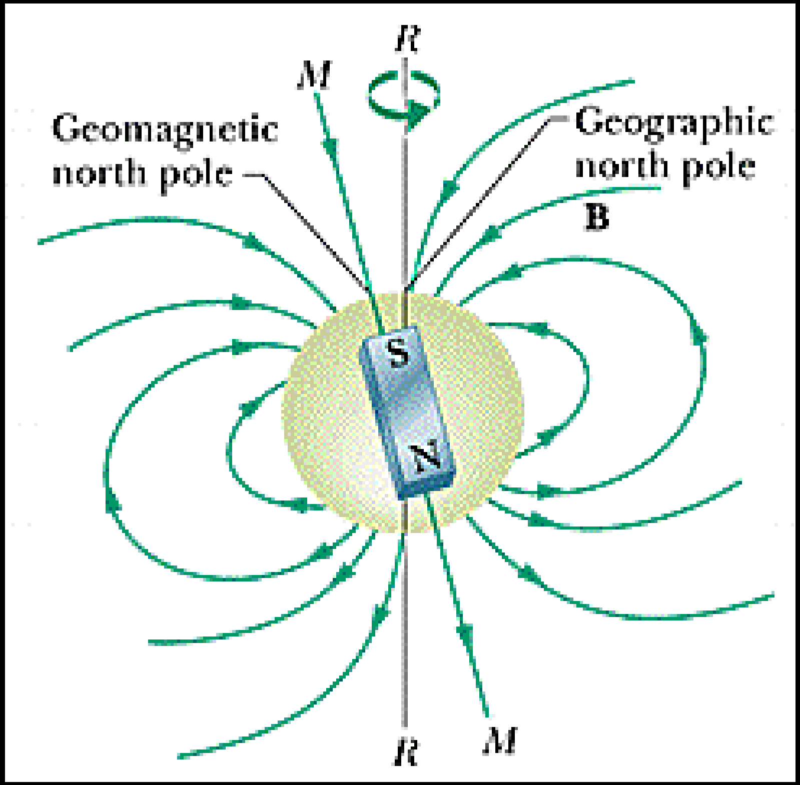
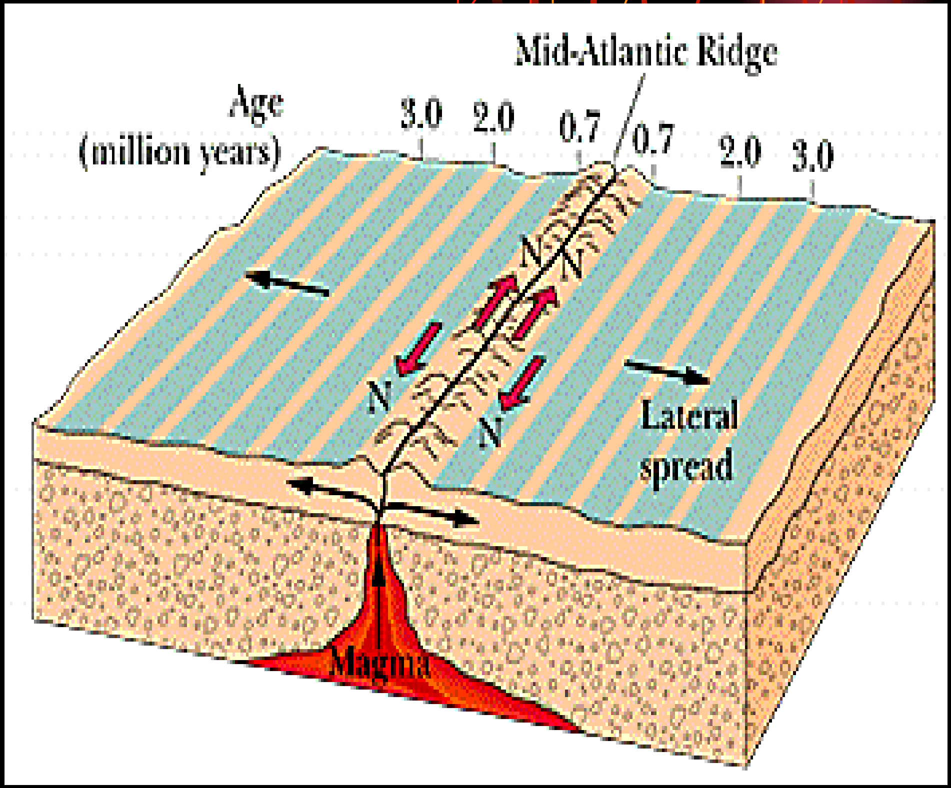
10 Magnetism of Matter 磁性
Electromagnetic Waves 電磁波

How can a clay-walled kiln reveal Earth’ s magnetic field of the past?

The Magnetic field of the Earth





The earth's dipole field

The mid-atlantic ridge

Sections

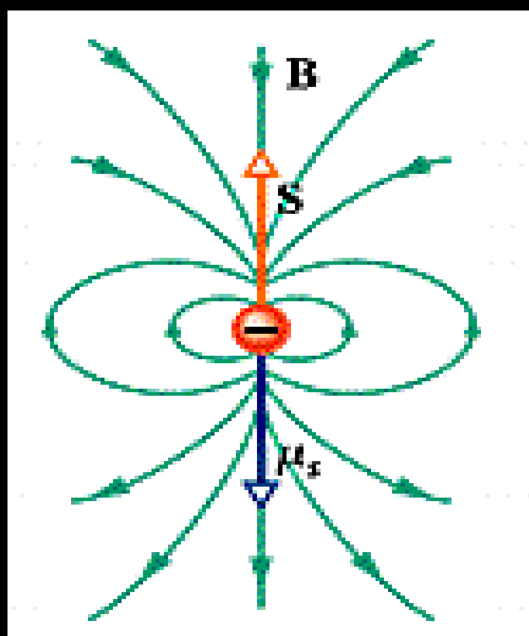
1. 物質的磁性 Magnetism
2. 麥斯威爾方程式 Maxwell’s Equations
3. 電磁波 Electromagnetic Waves
4. 偏振 Polarization

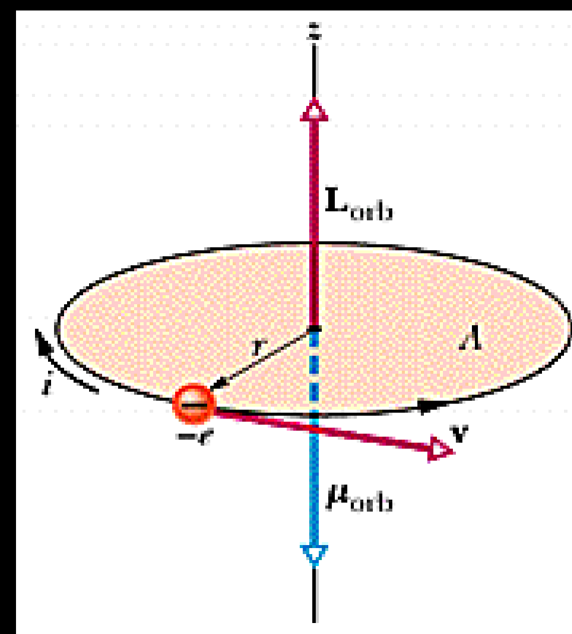
10-1 Magnetic Materials

- Diamagnetism (逆磁性)
- Paramagnetism (順磁性)
- Ferromagnetism (鐵磁性)

Magnetism and Electrons

- 除電子的運動(電流)外，其自旋與軌道運動亦可產生磁場





Loop Model for Electron Orbits

$$\mu_{orb} = iA, i = \frac{\text{charge}}{\text{time}} = \frac{e}{2\pi r / v}$$

$$\mu_{orb} = \frac{e}{2\pi r / v}\pi r^2 = \frac{evr}{2}$$

$$L_{orb} = mrv \rightarrow \vec{\mu}_{orb} = -\frac{e}{2m}\vec{L}_{orb}$$

Orbital Magnetic Dipole Moment

$$\vec{\mu}_{orb} = -\frac{e}{2m}\vec{L}_{orb}$$

$$L_{orb,z} = m_l \frac{h}{2\pi}$$

$$m_l = 0, \pm 1, \pm 2, \cdots, \pm(\text{limit})$$

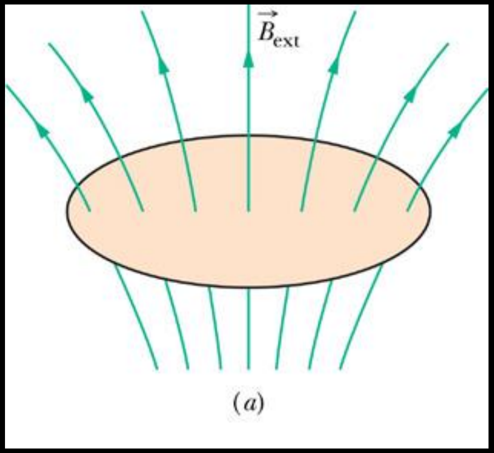
Spin Magnetic Dipole Moment and Bohr magneton

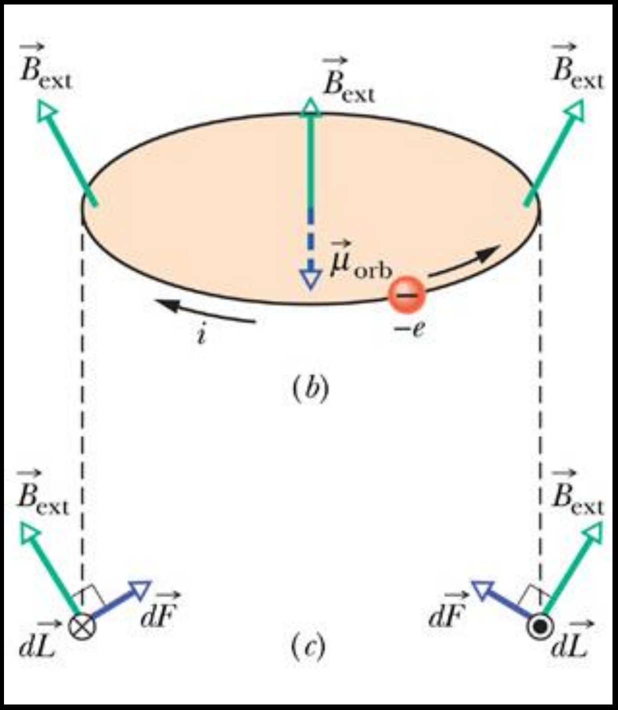
$$\vec{\mu}_s = -\frac{e}{m}\vec{S}, S_z = m_s \frac{h}{2\pi} \ (m_s = \pm\frac{1}{2})$$

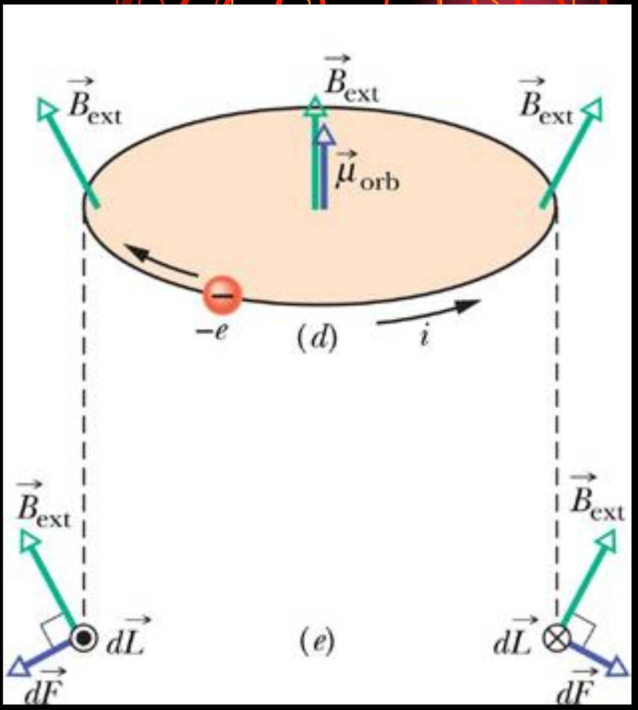
$$\mu_{s,z} = -\frac{e}{m} S_z = \pm \frac{eh}{4\pi m}$$

$$\mu_B = \frac{eh}{4\pi m} = 9.27 \times 10^{-24}\,\mathrm{J/T}$$

Loop Model in a Nonuniform Field







upward force

downward force

Loop Model in a Nonuniform Field

A diamagnetic material placed in an external magnetic field develops a magnetic dipole moment directed opposite .

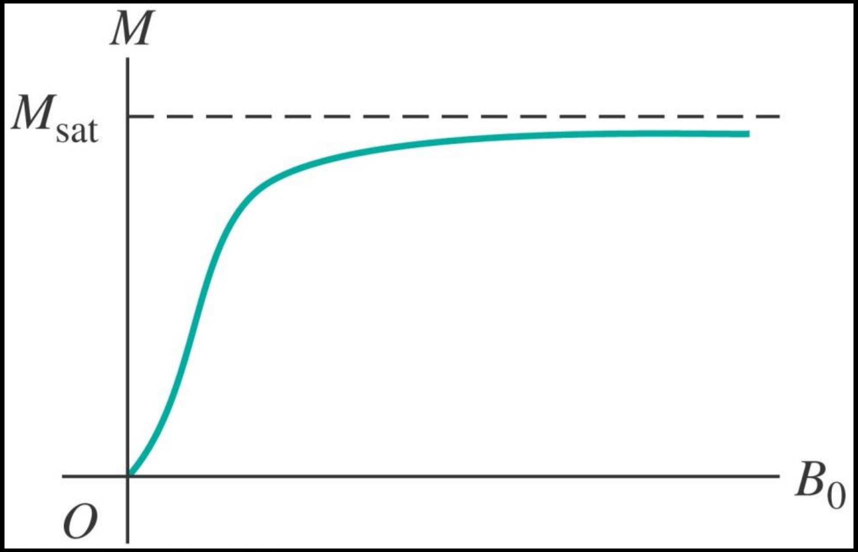
If the field is nonuniform, the diamagnetic material is repelled from a region of greater magnetic field toward a region of lesser field.

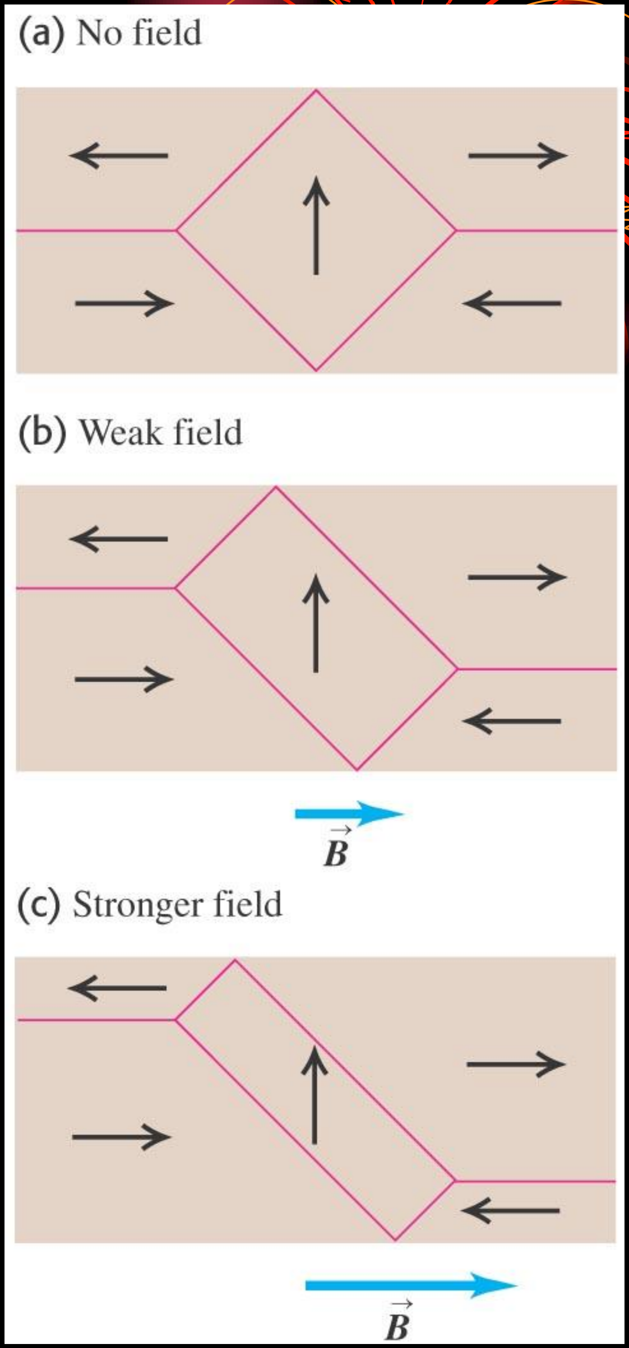
The Bohr magneton and paramagnetism

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

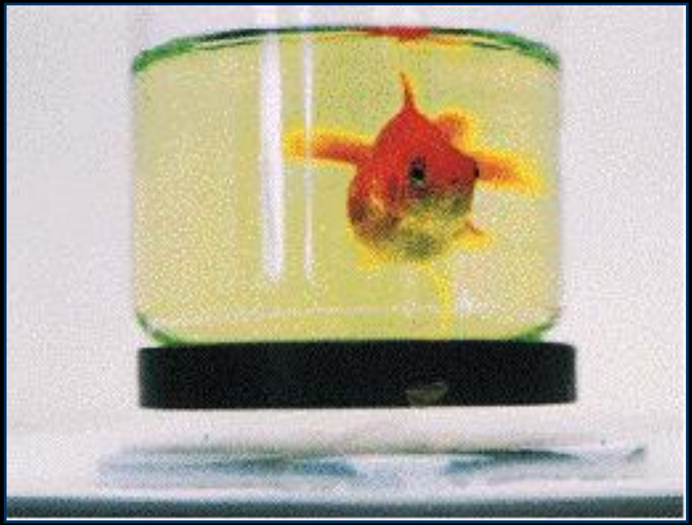
Diamagnetism and ferromagnetism





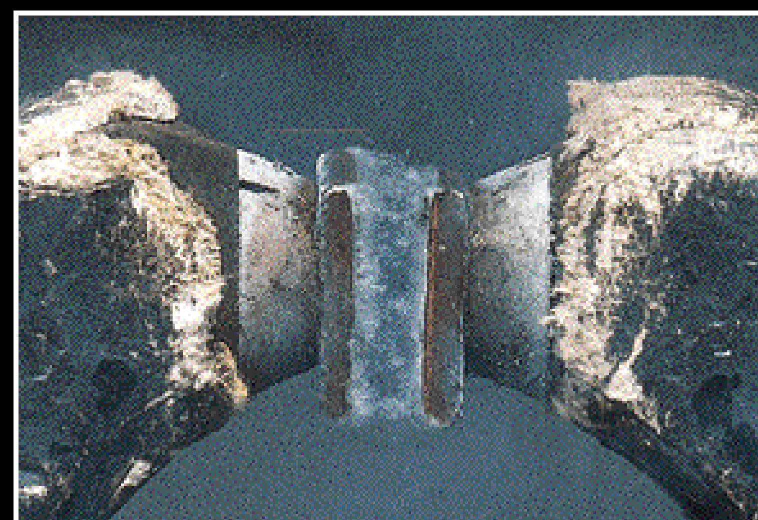
10-1.1 Diamagnetism

逆磁性材料產生之磁矩與外磁場逆向，如外磁場非均勻，其將受到由強磁場區到弱磁場區之斥力。



10-1.2 Paramagnetism

- 順磁性材料產生之磁矩與外磁場順向，如外磁場非均勻，其將受到由弱磁場區到強磁場區之吸力。



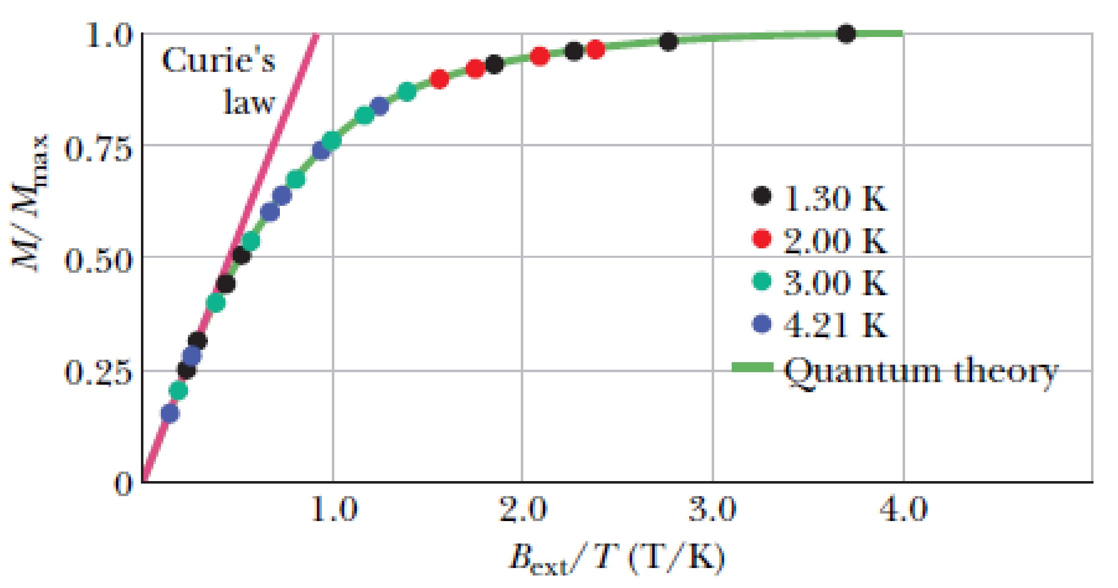
- 液態氧被吸在兩個磁極之間

10-1.2.1 Curie's Law

M : Magnetization

$$M = \frac{\text{measured magnetic moment}}{V}$$

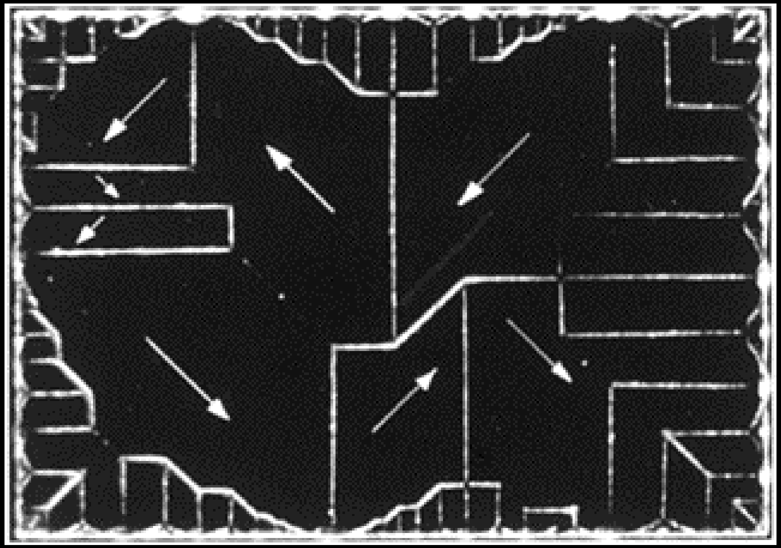
$$M = C\frac{B_{ext}}{T}$$

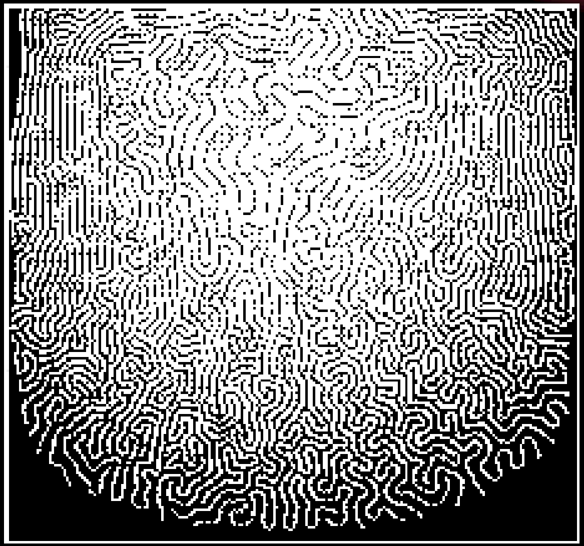


A magnetization curve for potassium chromium sulfate

10-1.3 Ferromagnetism

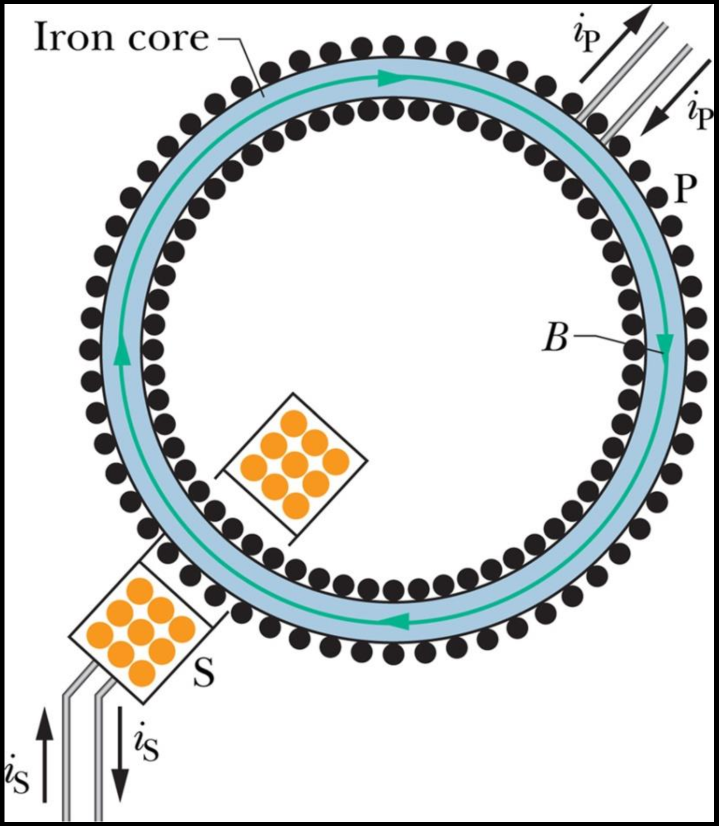
- 鎳的磁域(magnetic domain)





Ferrohydrodynamics

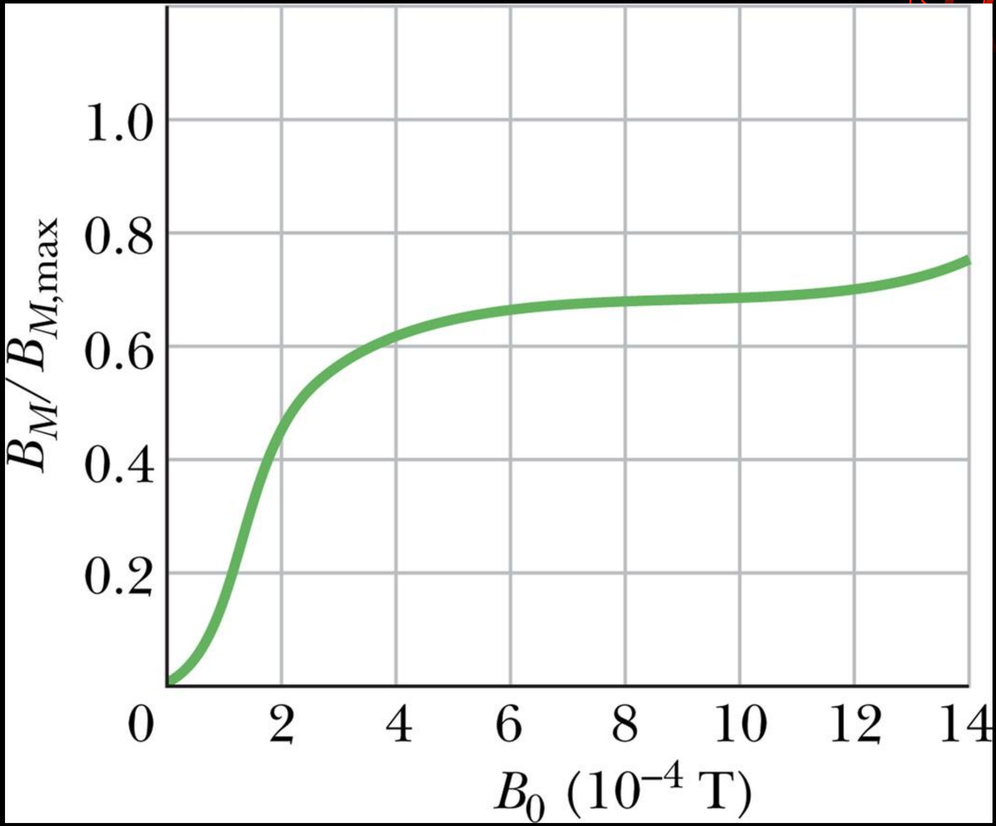
10-1.3.1 Rowland Ring



$$B_0 = \mu_0 i_P n$$

$$B = B_0 + B_M$$

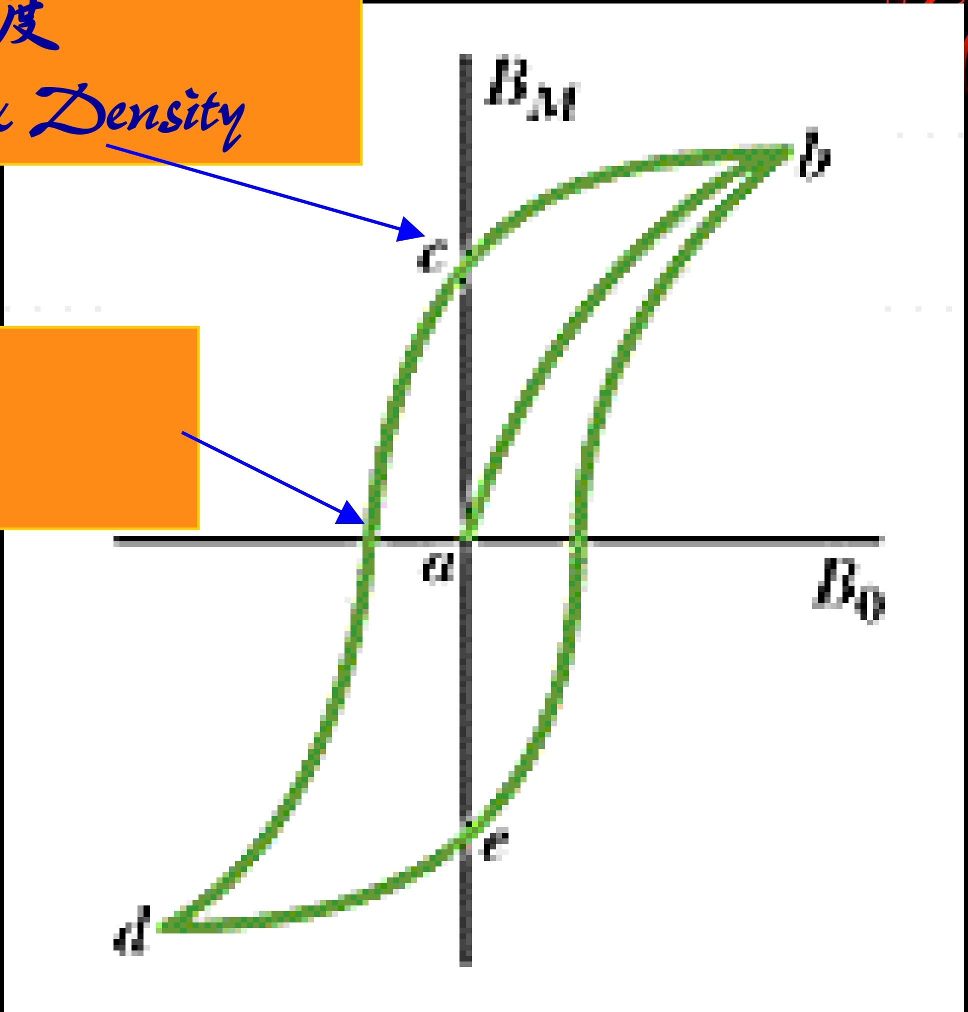
10-1.3.2 Magnetization Curve



10-1.3.3 Hysteresis (磁滯)

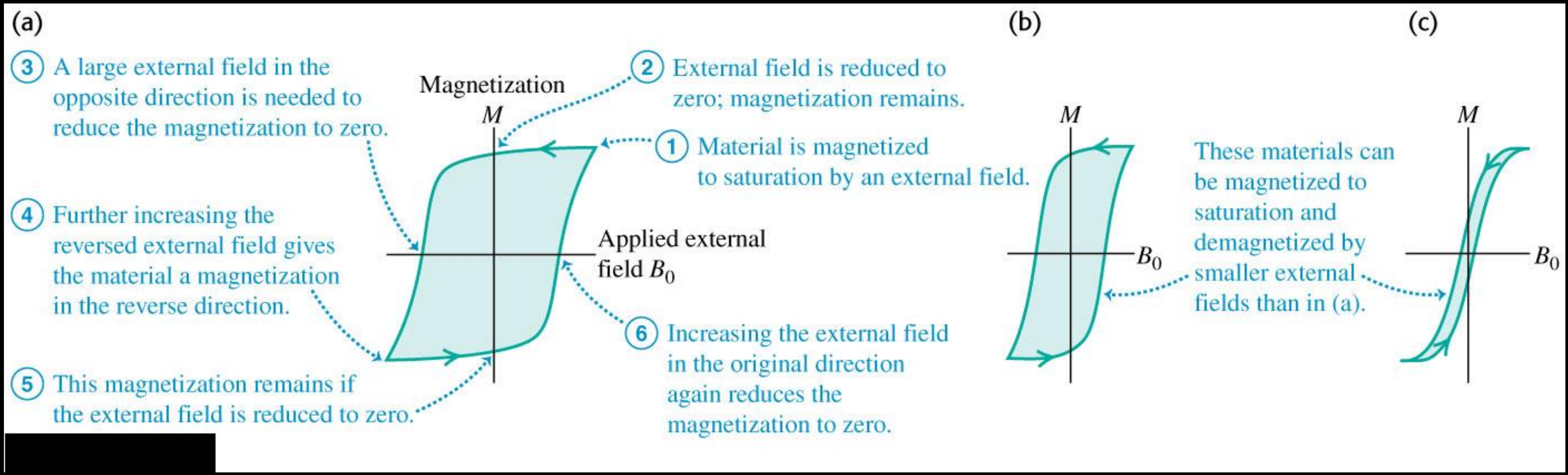
殘餘磁通密度
Residual Flux Density

矯頑磁力
coercive force

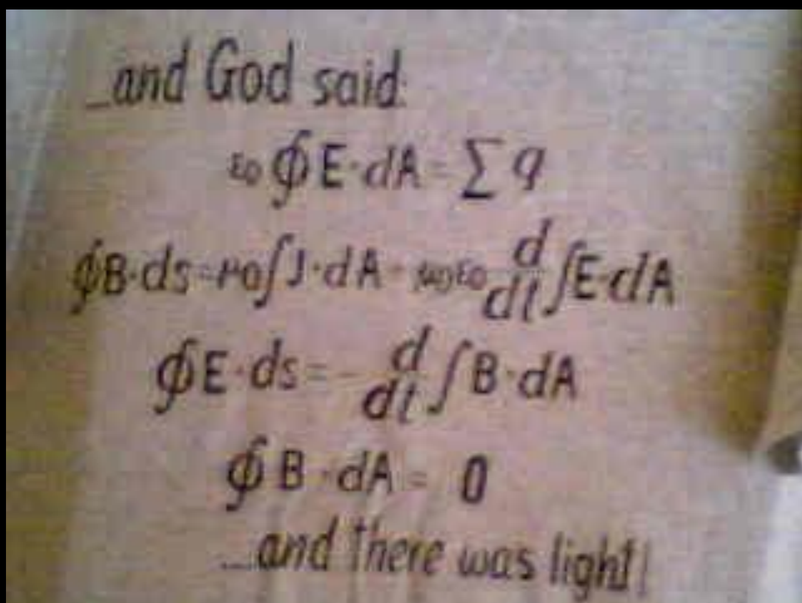


Hysteresis

- Read the text discussion of *hysteresis* using Figure 28.29 below.
- Follow Example 28.12.



10-2 Maxwell's Equations



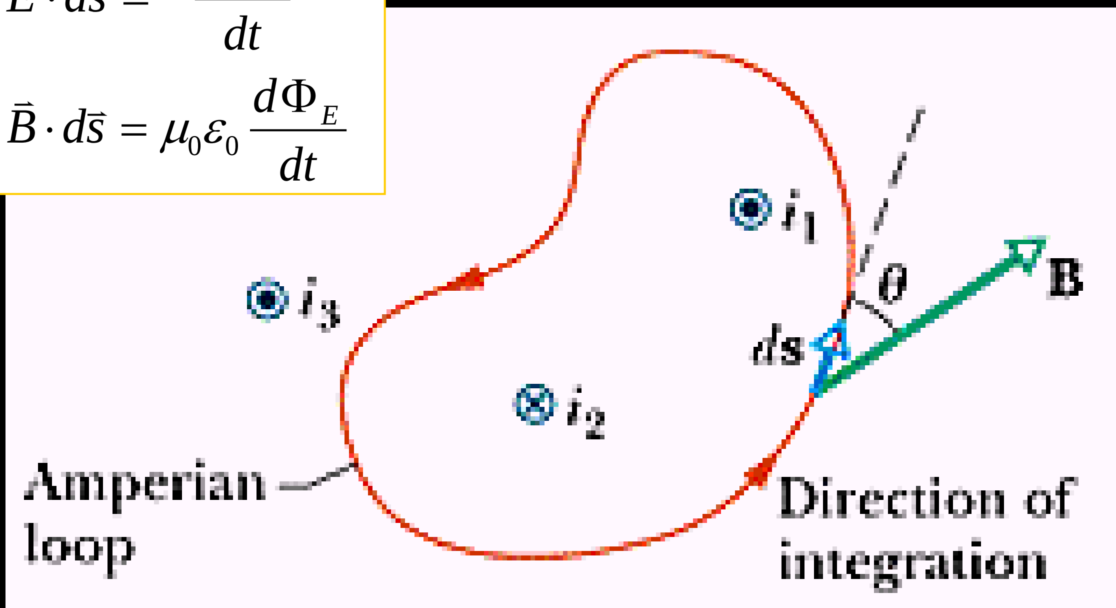
10-2.1 線積分與面積分 (安培迴路和高斯面)

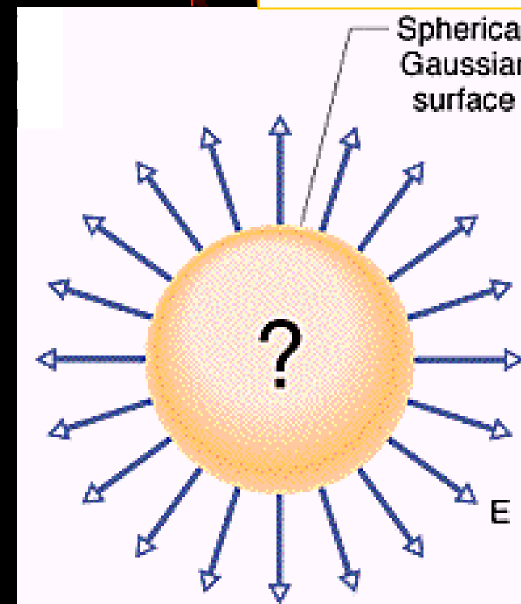
$$\Phi_B = \oint \vec{B} \cdot d\vec{A} = 0$$

$$\Phi_E = \oint \vec{E} \cdot d\vec{A} = q/\varepsilon_0$$

$$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt}$$

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt}$$

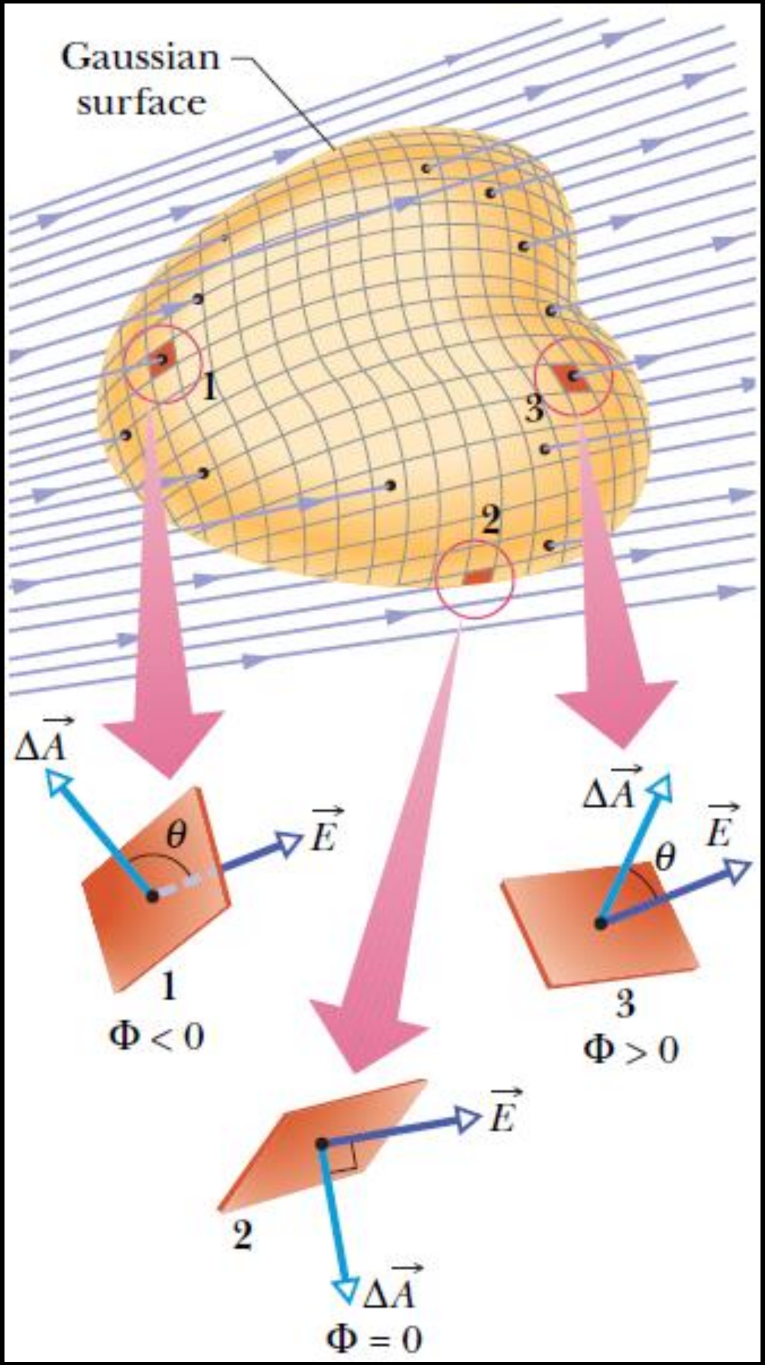


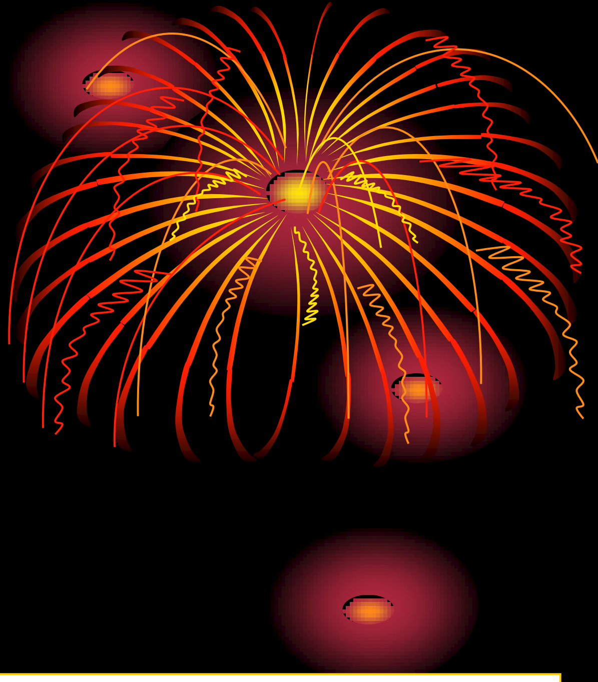


磁場環流量 (安培定律)　　電場通量

電場環流量 **法拉第定律** 磁場通量

高斯面





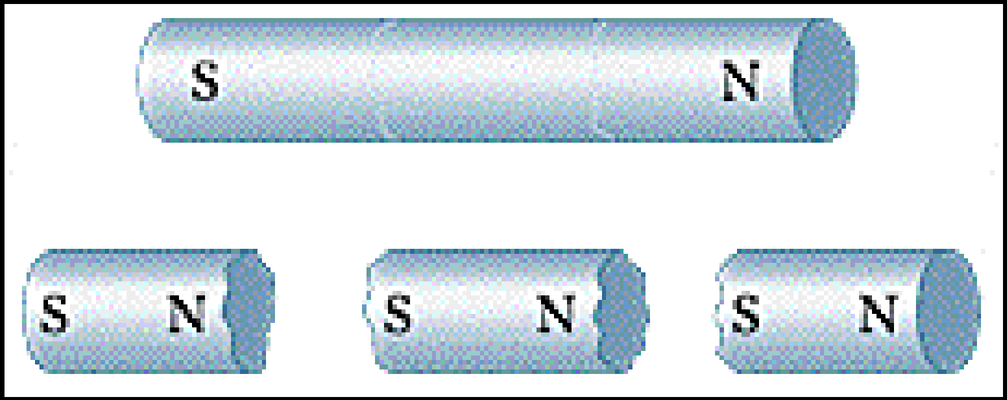
$$\Phi_B = \oint \vec{B} \cdot d\vec{A} = 0$$

$$\Phi_E = \oint \vec{E} \cdot d\vec{A} = q / \varepsilon_0$$

$\Delta\vec{A} \Rightarrow d\vec{A}$

10-2.2 Magnets and magnetic flux (磁鐵和磁通量)

Magnetic dipole: north/south pole

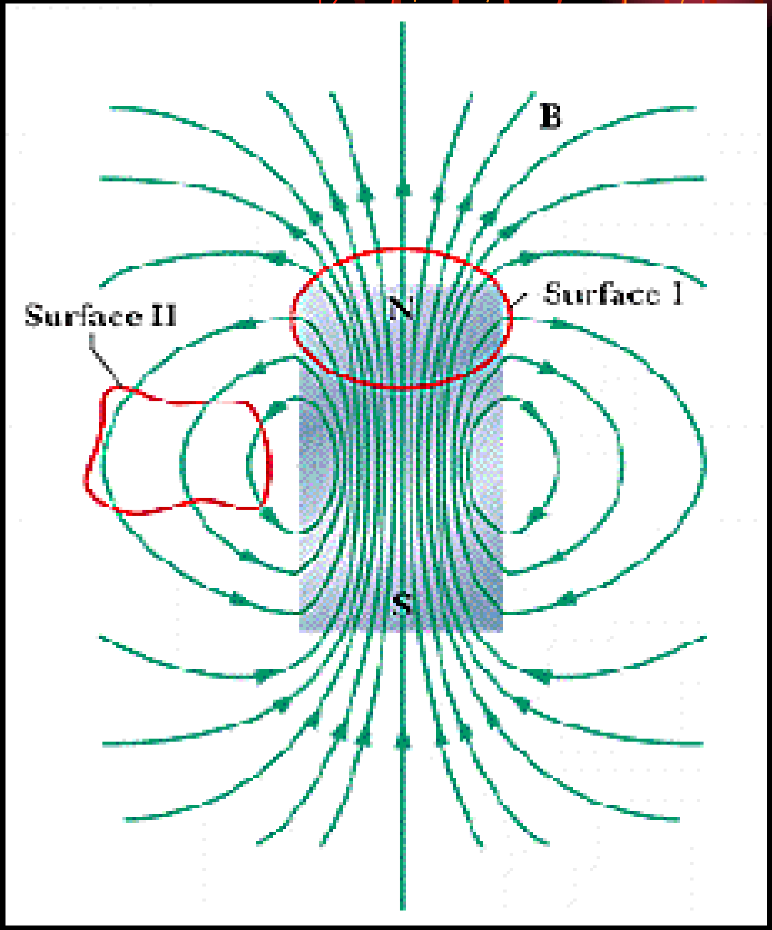


10-2.3 Gauss' Law for Magnetic Fields

The net magnetic flux thru any closed Gaussian surface is zero.

$$\Phi_B = \oint \vec{B} \cdot d\vec{A} = 0$$

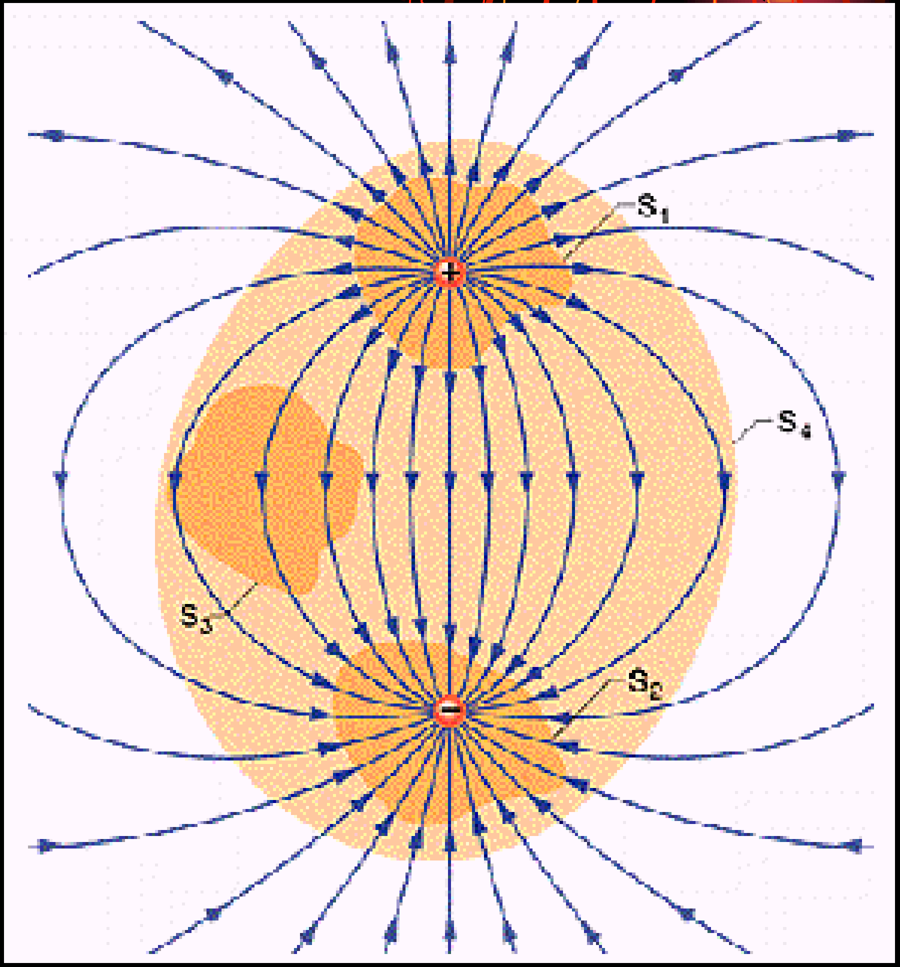
$$\Phi_E = \oint \vec{E} \cdot d\vec{A} = q / \varepsilon_0$$



10-2.4 Gauss' Law for electric Fields

Flux ↔ enclosed charge

$$\varepsilon_0 \Phi = \varepsilon_0 \oint \vec{E} \cdot d\vec{A} = q_{enc}$$



10-2.5 Induced Magnetic Fields

$$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_B}{dt} \qquad \text{(Faraday's Law of inductin)}$$

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt} \qquad \text{(Maxwell's Law of inductin)}$$

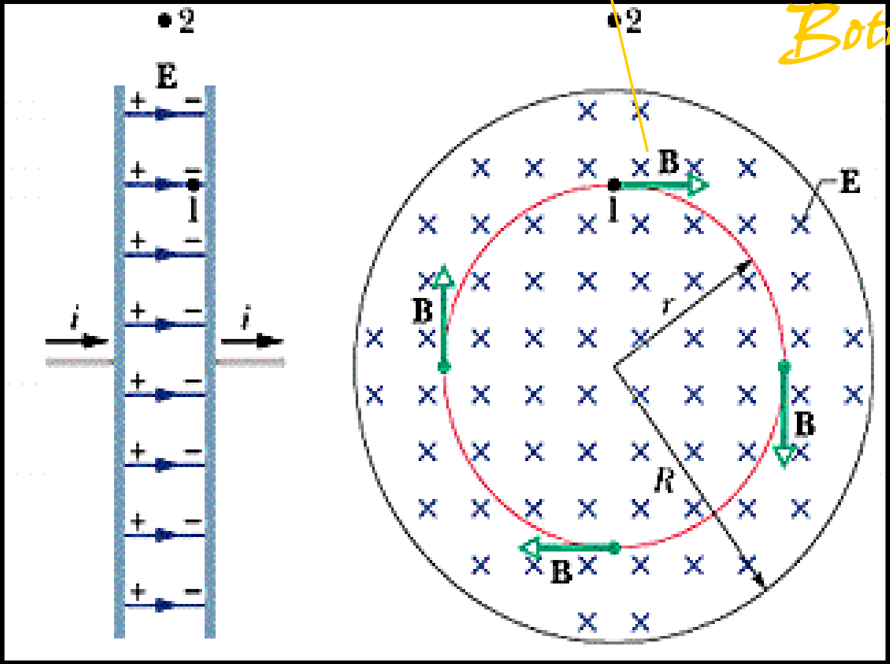
3 ways to produce a magnetic field: by an electric current, by a magnetic material, and by induction.

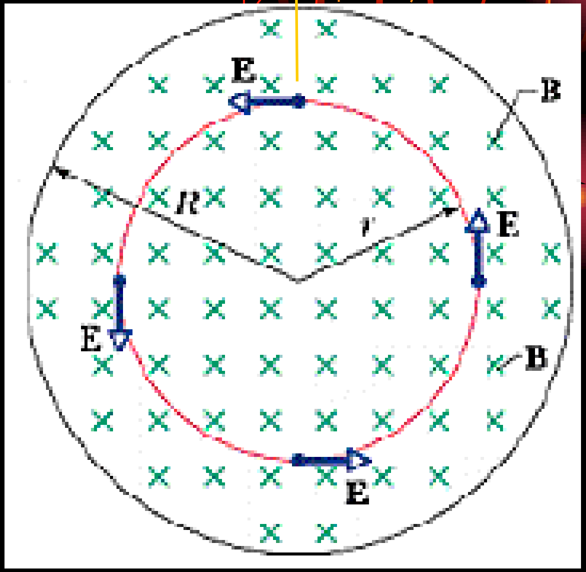
induced B field

induced E field

10-2.6 Ampere-Maxwell Law

Both increasing





$$\oint \vec{B}\cdot d\vec{s} = \mu_0 i_{enc}$$ (Ampere's Law)

$$\oint \vec{B}\cdot d\vec{s} = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt} + \mu_0 i_{enc}$$ (Ampere-Maxwell Law)

10-2.7 Find B(r)

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt}$$

$$B \cdot 2\pi r = \mu_0 \varepsilon_0 \frac{d}{dt}(\pi r^2 E) = \mu_0 \varepsilon_0 \pi r^2 \frac{dE}{dt}$$

$$B = \frac{\mu_0 \varepsilon_0 r}{2} \frac{dE}{dt} \qquad \text{(for r} \leq \text{R)}$$

$$B \cdot 2\pi r = \mu_0 \varepsilon_0 \frac{d}{dt}(\pi R^2 E) = \mu_0 \varepsilon_0 \pi R^2 \frac{dE}{dt}$$

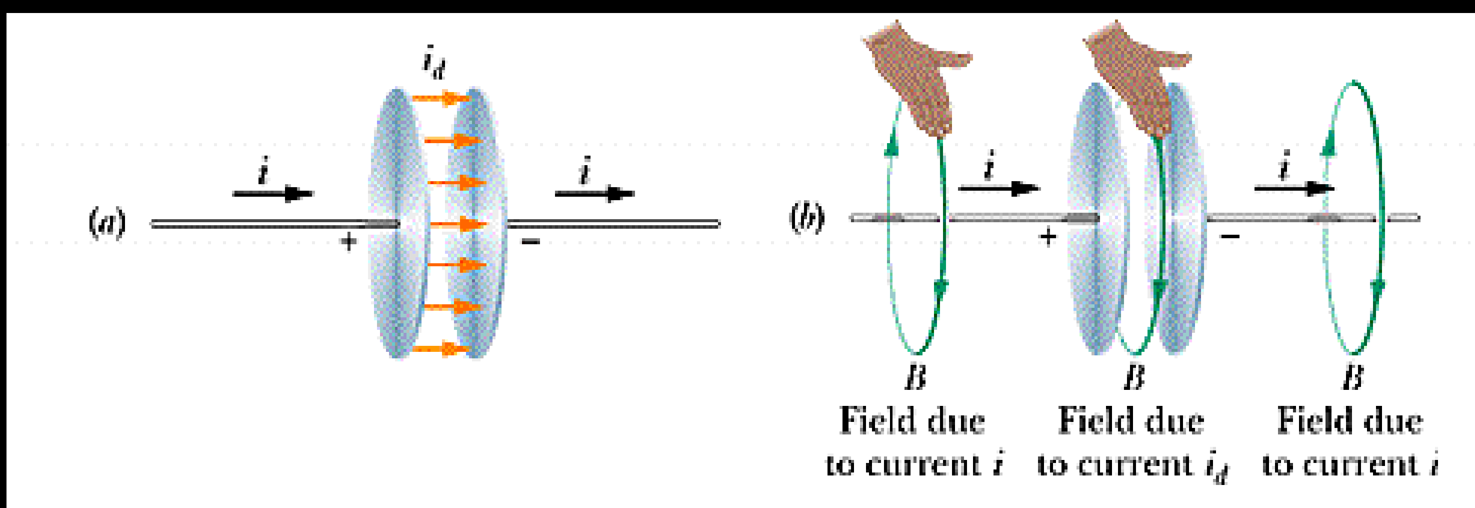
$$B = \frac{\mu_0 \varepsilon_0 R^2}{2r} \frac{dE}{dt} \qquad \text{(for r} \geq \text{R)}$$

10-2.8 Displacement Current

$$\oint \vec{B}\cdot d\vec{s} = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt} + \mu_0 i_{enc}$$

$$i_d = \varepsilon_0 \frac{d\Phi_E}{dt}$$

$$\oint \vec{B}\cdot d\vec{s} = \mu_0 i_{d,enc} + \mu_0 i_{enc}$$



10-2.9 Maxwell's Equations

TABLE 32-1 MAXWELL'S EQUATIONS [a]

NAME	EQUATION
Gauss' law for electricity	$\oint \mathbf{E} \cdot d\mathbf{A} = q/\epsilon_0$
Relates net electric flux to net enclosed electric charge	
Gauss' law for magnetism	$\oint \mathbf{B} \cdot d\mathbf{A} = 0$
Relates net magnetic flux to net enclosed magnetic charge	
Faraday's law	$\oint \mathbf{E} \cdot d\mathbf{s} = -\frac{d\Phi_B}{dt}$
Relates induced electric field to changing magnetic flux	
Ampere-Maxwell law	$\oint \mathbf{B} \cdot d\mathbf{s} = \mu_0 \epsilon_0 \frac{d\Phi_E}{dt} + \mu_0 i_{enc}$
Relates induced magnetic field to changing electric flux and to current	

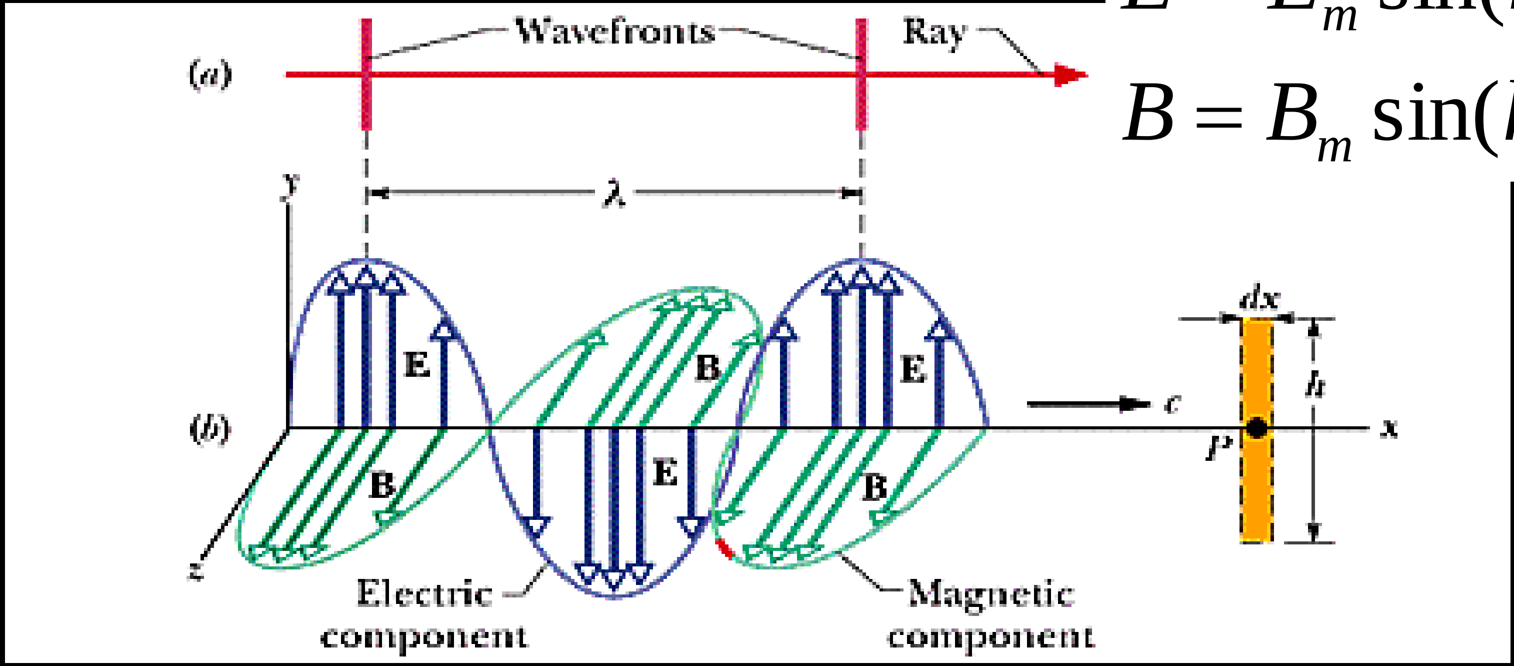
[a] Written on the assumption that no dielectric or magnetic materials are present.

10-3 Electromagnetic Waves

- The oscillating E and B Fields
- A Most Curious Wave
  - The ether (以太)

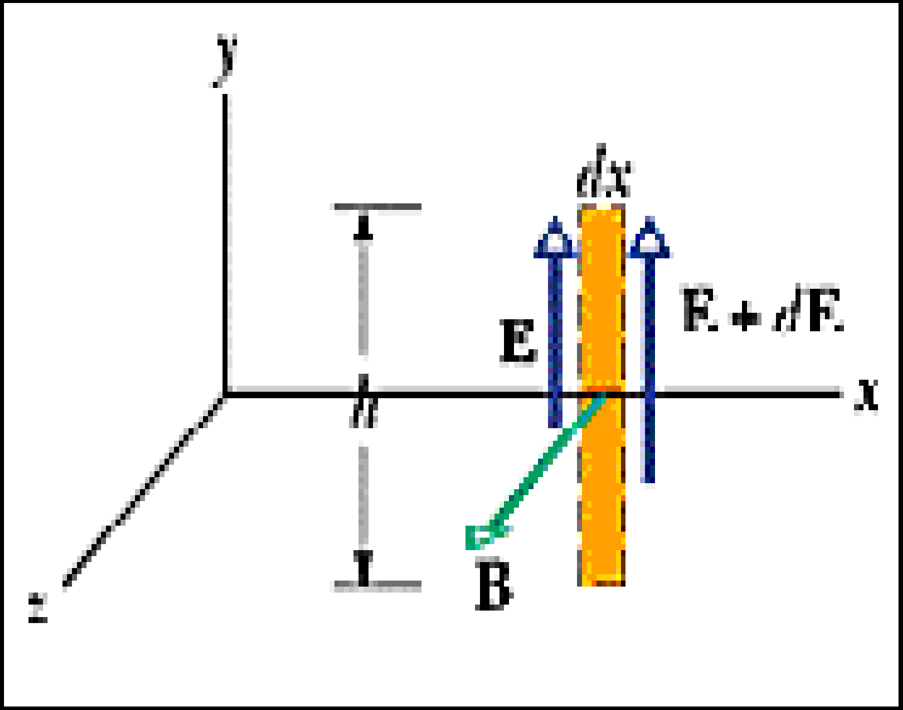
$$E = E_m \sin(kx - \omega t)$$

$$B = B_m \sin(kx - \omega t)$$



34-3 The Traveling Electromagnetic Wave

- The induced electric field:



$$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi}{dt}$$

$$\oint \vec{E} \cdot d\vec{s} = (E + dE)h - Eh$$

$$= h\,dE$$

$$\oint \vec{E}\cdot d\vec{s} = -\frac{d\Phi}{dt}$$

$$\oint \vec{E}\cdot d\vec{s} = (E+dE)h - Eh$$

$$= hdE$$

$$\Phi_B = (B)(hdx),\ \frac{d\Phi_B}{dt} = hdx\frac{dB}{dt}$$

$$hdE = -hdx\frac{dB}{dt},\ \frac{dE}{dx} = -\frac{dB}{dt}$$

$$\frac{dE}{dx} = -\frac{dB}{dt} \rightarrow \frac{\partial E}{\partial x} = -\frac{\partial B}{\partial t}$$

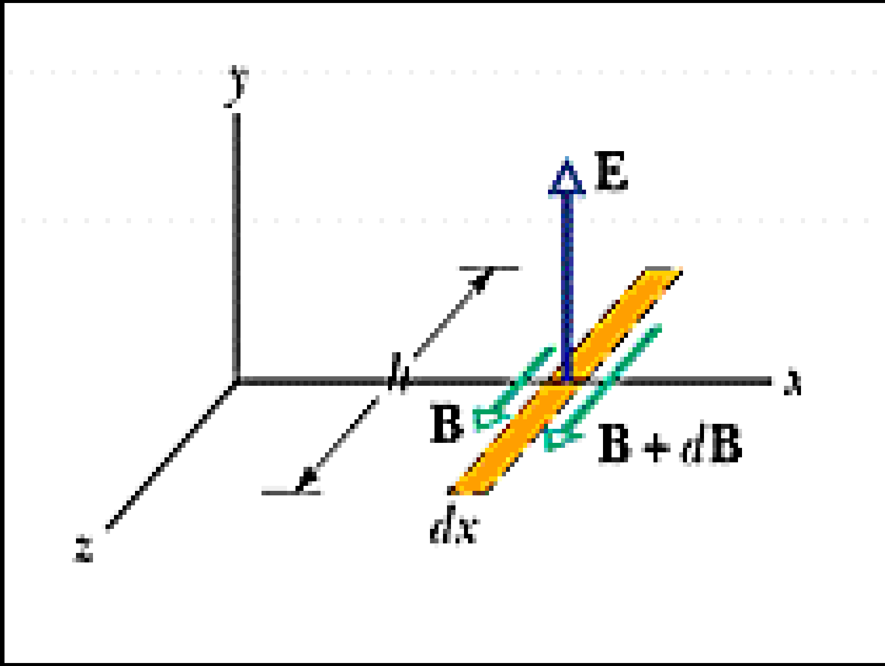
$$\frac{\partial E}{\partial x} = kE_m \cos(kx - \omega t)$$

$$\frac{\partial B}{\partial t} = -\omega B_m \cos(kx - \omega t)$$

$$kE_m \cos(kx - \omega t) = \omega B_m \cos(kx - \omega t)$$

$$\rightarrow \frac{E_m}{B_m} = c$$

- *The induced magnetic field:*



$$\oint \vec{B}\cdot d\vec{s} = \mu_0\varepsilon_0 \frac{d\Phi_E}{dt}$$

$$\oint \vec{B}\cdot d\vec{s} = -(B+dB)h + Bh$$

$$= -hdB$$

$$\Phi_E = (E)(hdx), \quad \frac{d\Phi_E}{dt} = hdx\frac{dE}{dt}$$

$$-hdB = \mu_0\varepsilon_0(hdx\frac{dE}{dt}) \rightarrow -\frac{\partial B}{\partial t} = \mu_0\varepsilon_0\frac{\partial E}{\partial t}$$

$$-kB_m\cos(kx-\omega) = -\mu_0\varepsilon_0\omega\cos(kx-\omega t)$$

$$\frac{E_m}{B_m} = \frac{1}{\mu_0\varepsilon_0(\omega/k)} = \frac{1}{\mu_0\varepsilon_0 c}, \; \mathrm{c} = \frac{1}{\sqrt{\mu_0\varepsilon_0}}$$

10-3.1 Characteristics

- Light ↔ Electromagnetic Waves
- Hertz (赫茲) – Radio Waves
- The Electromagnetic Spectrum
- The Relative Sensitivity of Human eyes
  430nm – 690nm

10-3.2 Maxwell's Rainbow

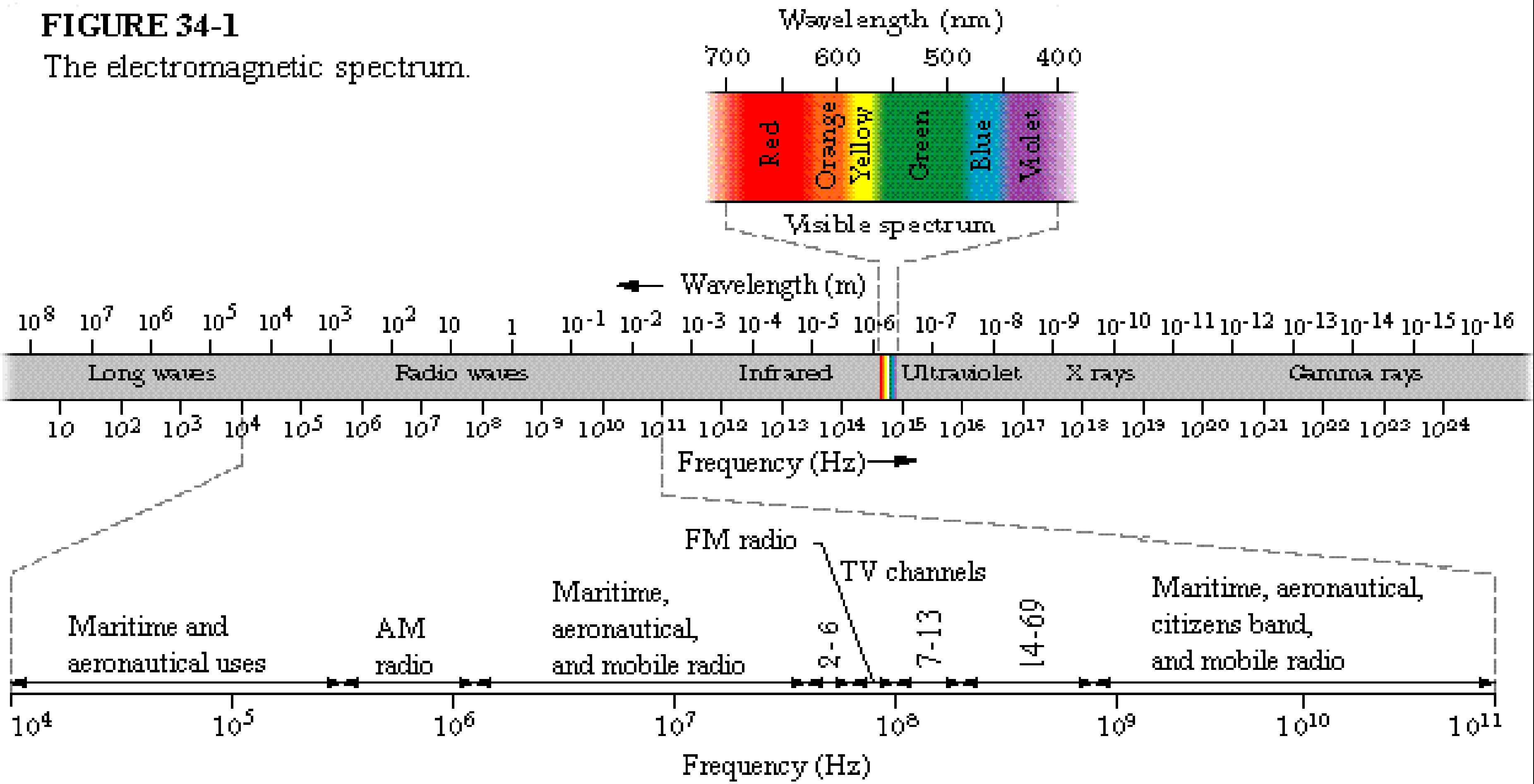


FIGURE 34-1
The electromagnetic spectrum.

10-3.3 Comets

What shapes the curved dust tail of a comet?

10-3.3.1 Radiation Pressure

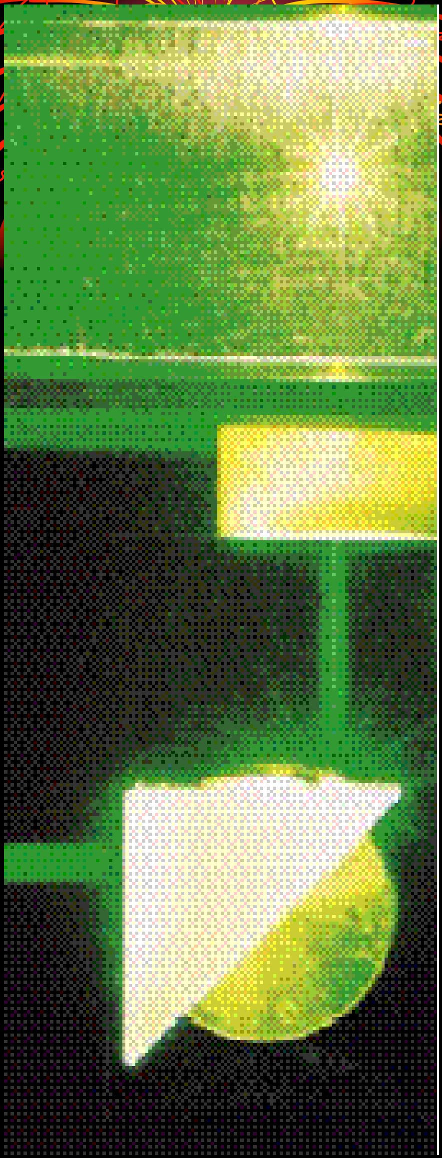
- Momentum Gain of an Object

$$\Delta p = \frac{\Delta U}{c} \qquad \text{(total absorption)}$$

$$\Delta p = \frac{2\Delta U}{c} \qquad \text{(total reflection)}$$

Momentum change

energy change



- ***The Force Exerted by Radiation***

$$F = \frac{\Delta p}{\Delta t} \qquad \Delta U = IA\Delta t \qquad \Delta p = \frac{\Delta U}{c} = \frac{IA\Delta t}{c}$$

$$F = \frac{IA}{c} \qquad p_r = \frac{I}{c} \qquad \text{(total absorption)}$$

$$F = \frac{2IA}{c} \qquad p_r = \frac{2I}{c} \qquad \text{(total reflection)}$$

- The size of comet particles

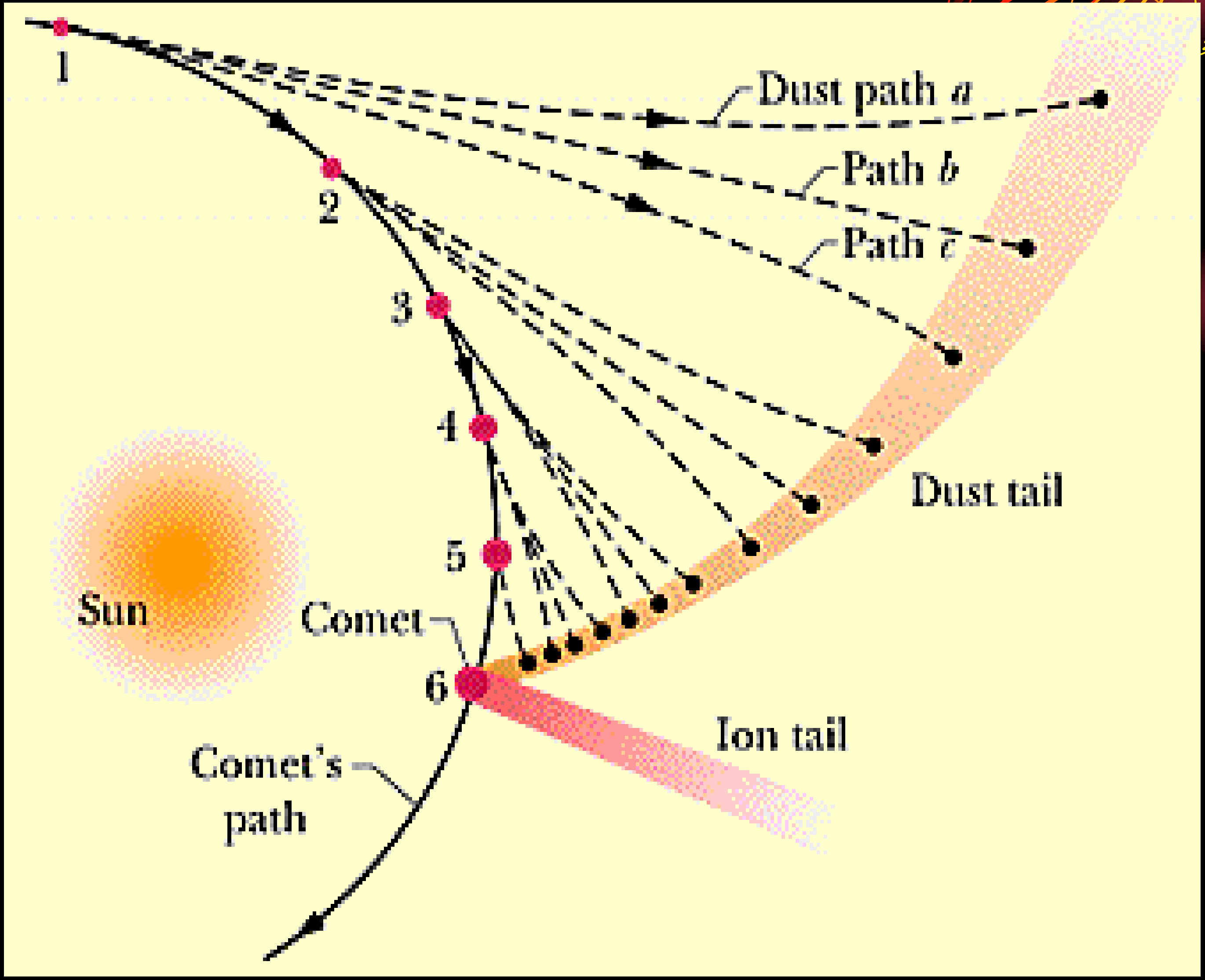
$$I = \frac{P_S}{4\pi r^2} \qquad F_r = \frac{IA}{c}$$

$$F_r = \frac{I\pi R^2}{c} = \frac{P_S R^2}{4cr^2}$$

$$F_g = \frac{GM_S m}{r^2} = \frac{4GM_S \rho\pi R^3}{3r^2}$$

$$F_r = F_g \to R = \frac{3P_S}{16\pi c\rho GM_S} = 1.7\times10^{-7}\,m$$

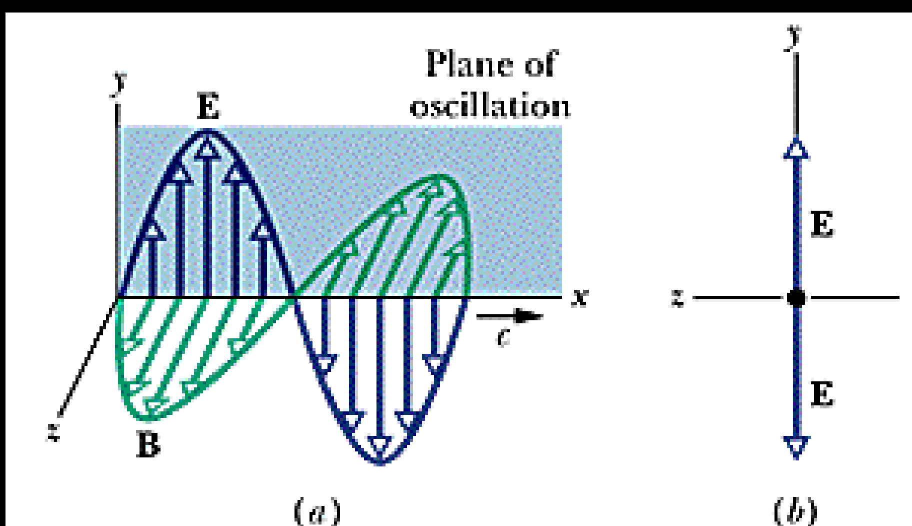
光壓 αR^{2}重力 αR^3

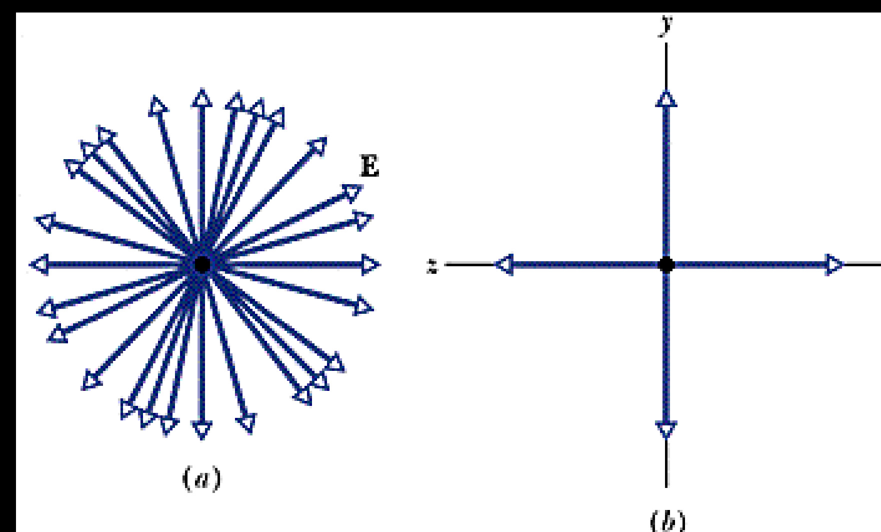


1
2
3
4
5
6
Dust path a
Path b
Path c
Dust tail
Sun
Comet
Ion tail
Comet's path

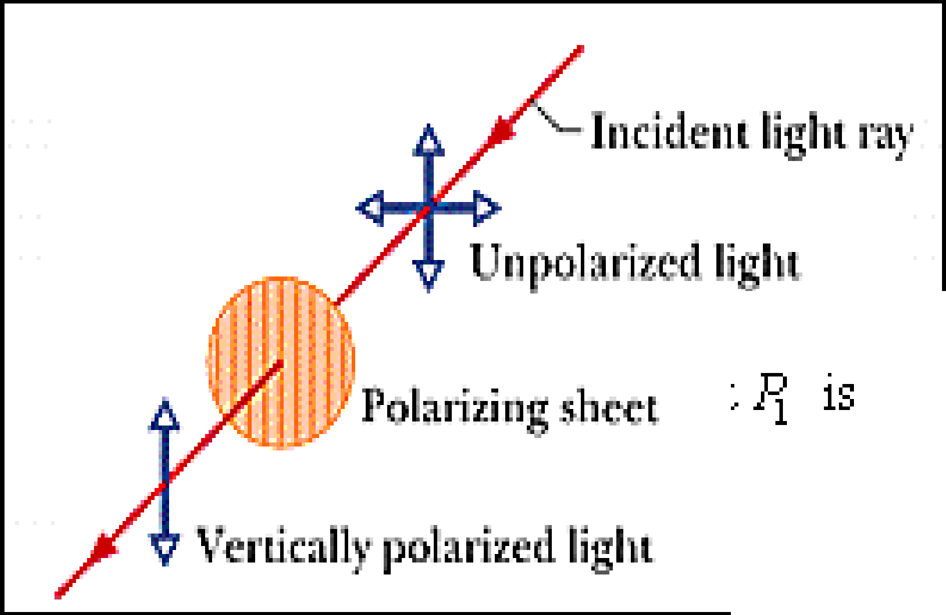
10-4 Polarization (偏振)

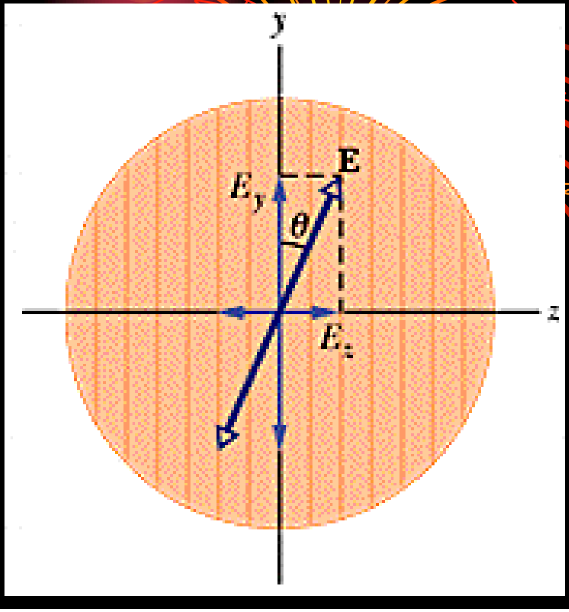
- Polarized Light
- The Plane of Polarization
- Linear, Circular and Elliptical polarization

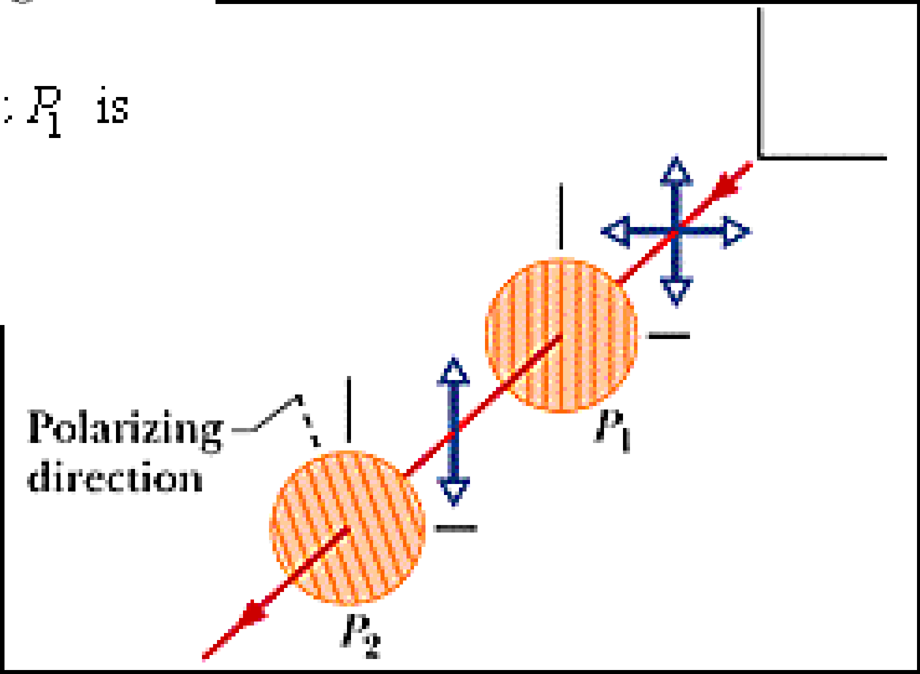




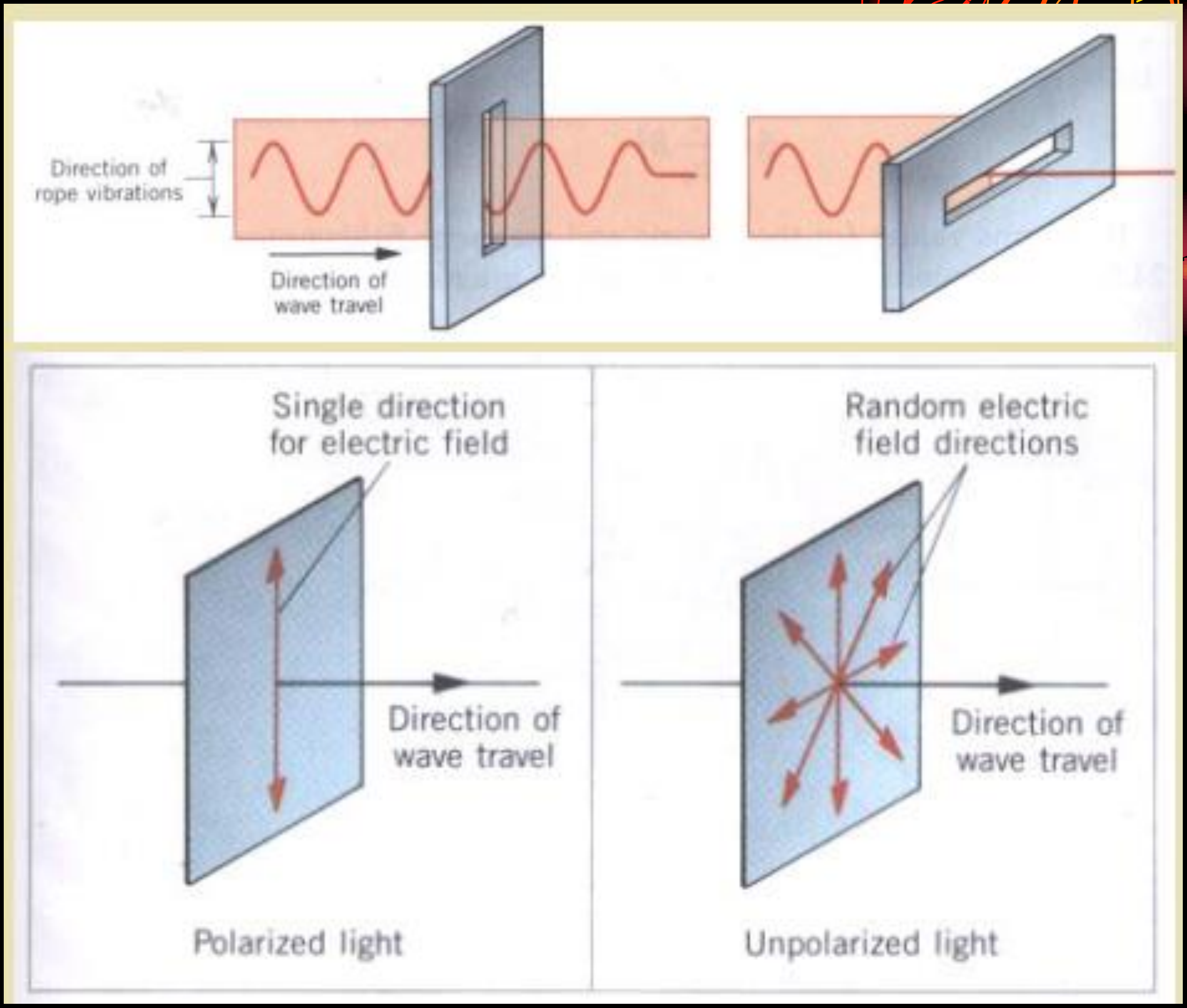
偏振片


Incident light ray
Unpolarized light
Polarizing sheet
Vertically polarized light

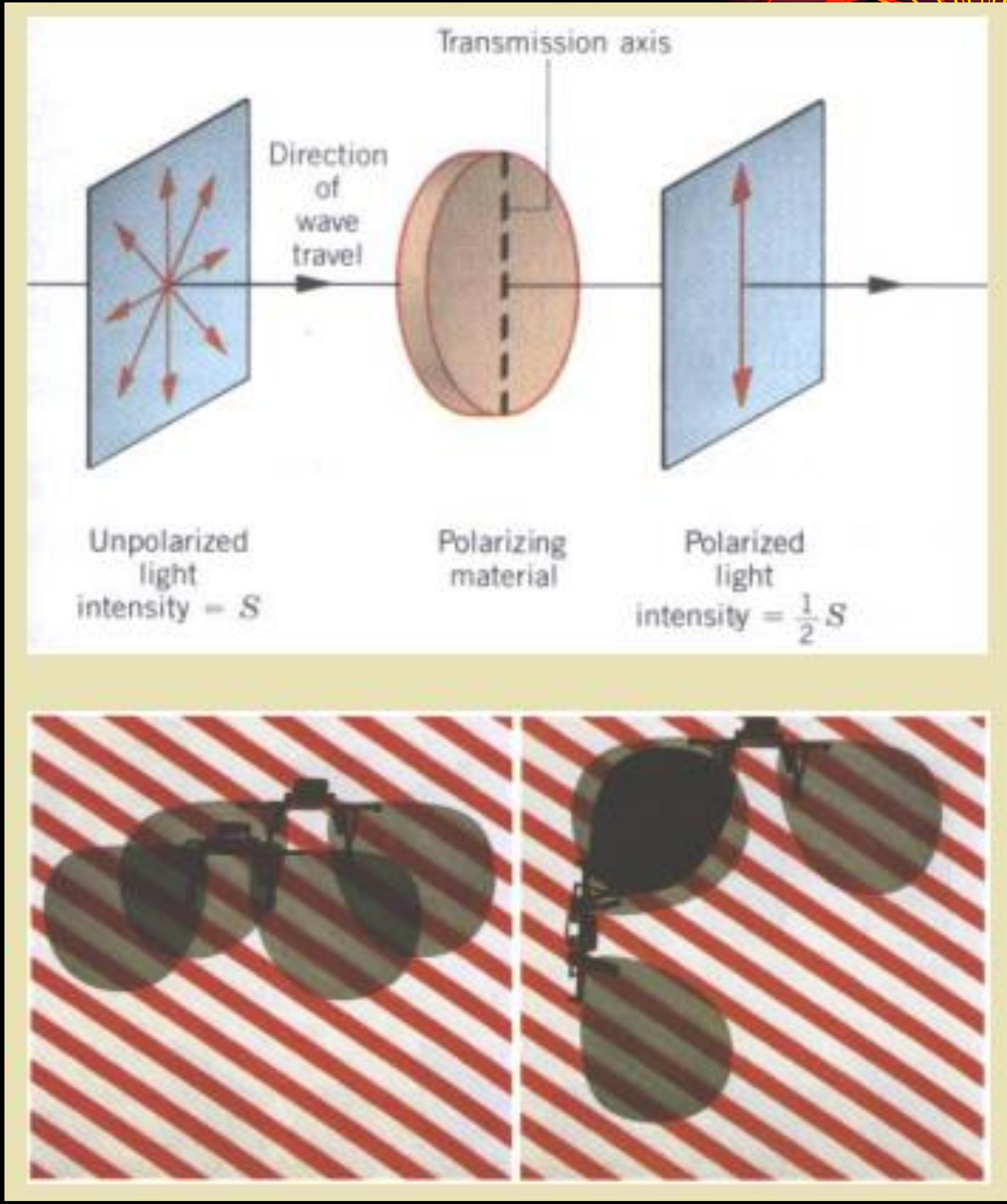

y
E
E_y
θ
z
E_z


: P_1 is
Polarizing direction
P_1
P_2

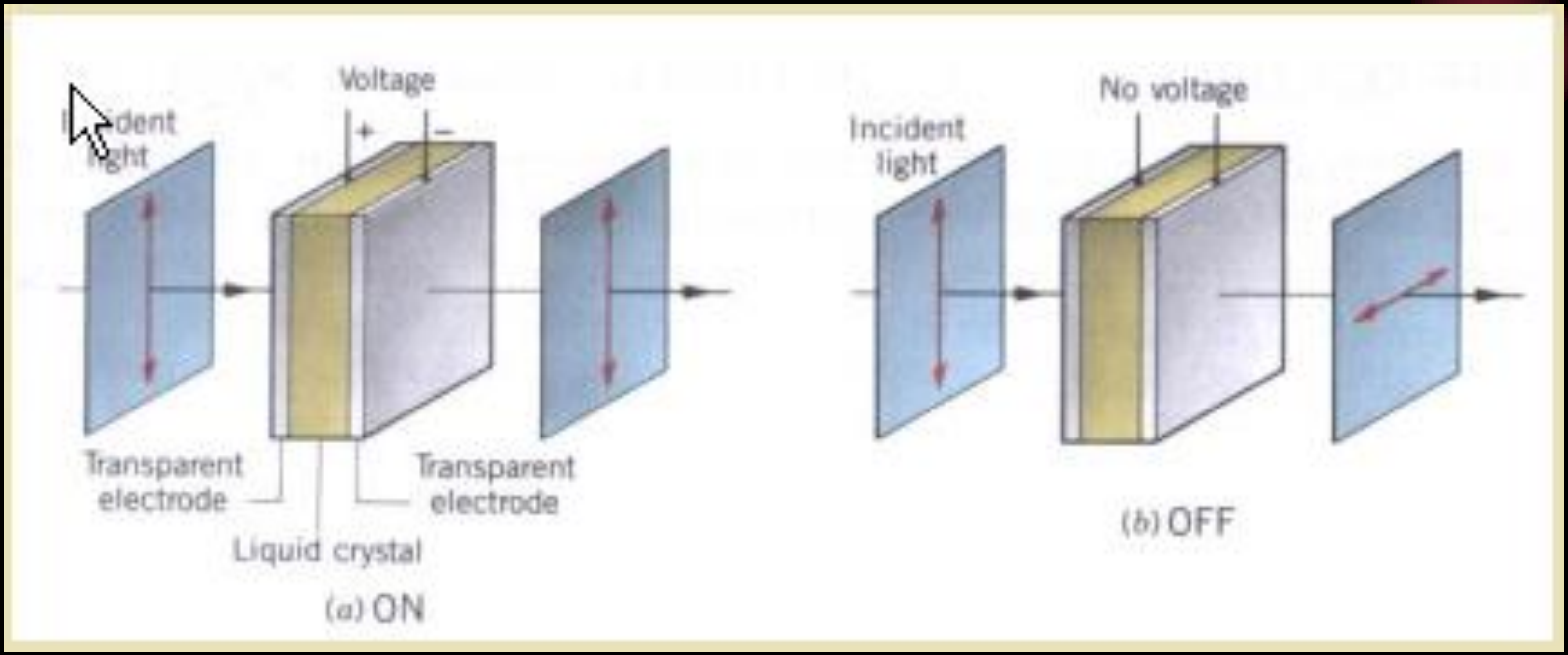
Polarization of Light



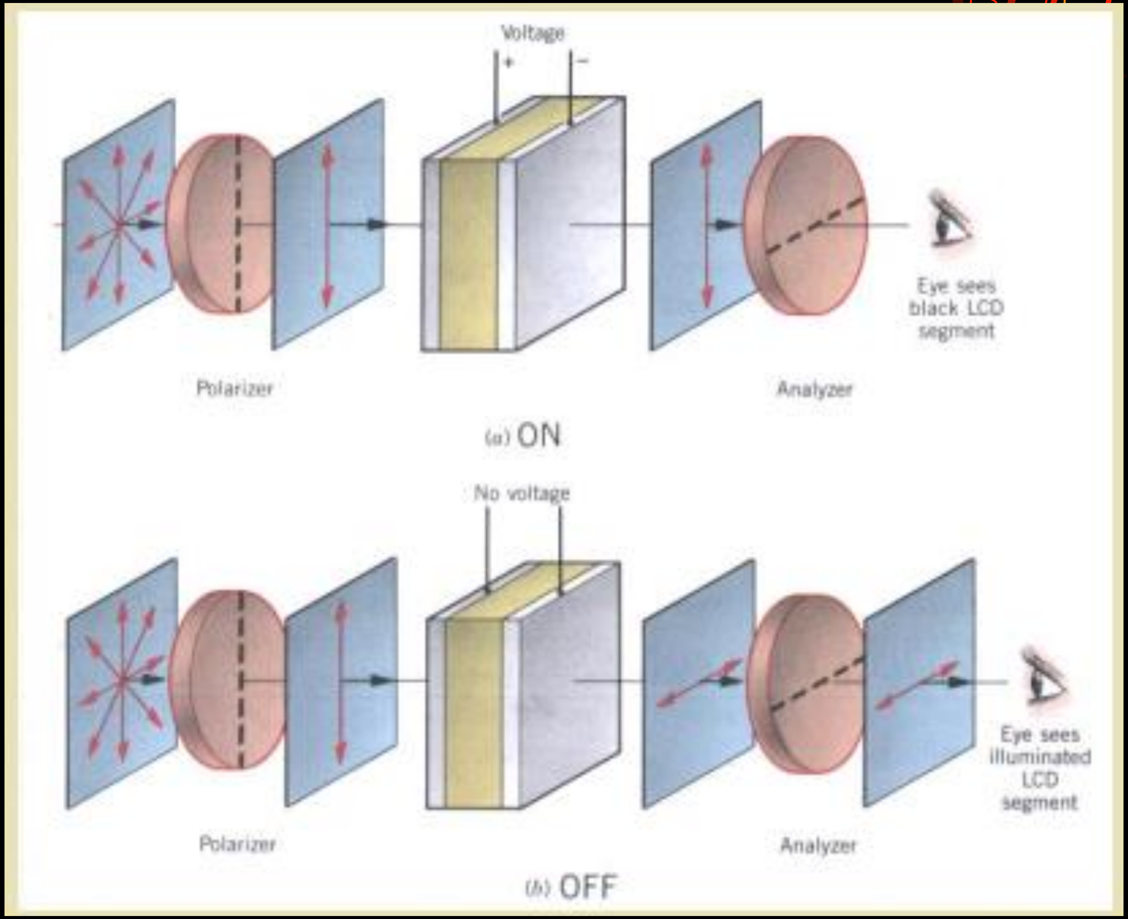
偏振與太陽眼鏡


Transmission axis
Direction of wave travel
Unpolarized light intensity = S
Polarizing material
Polarized light intensity = ½ S

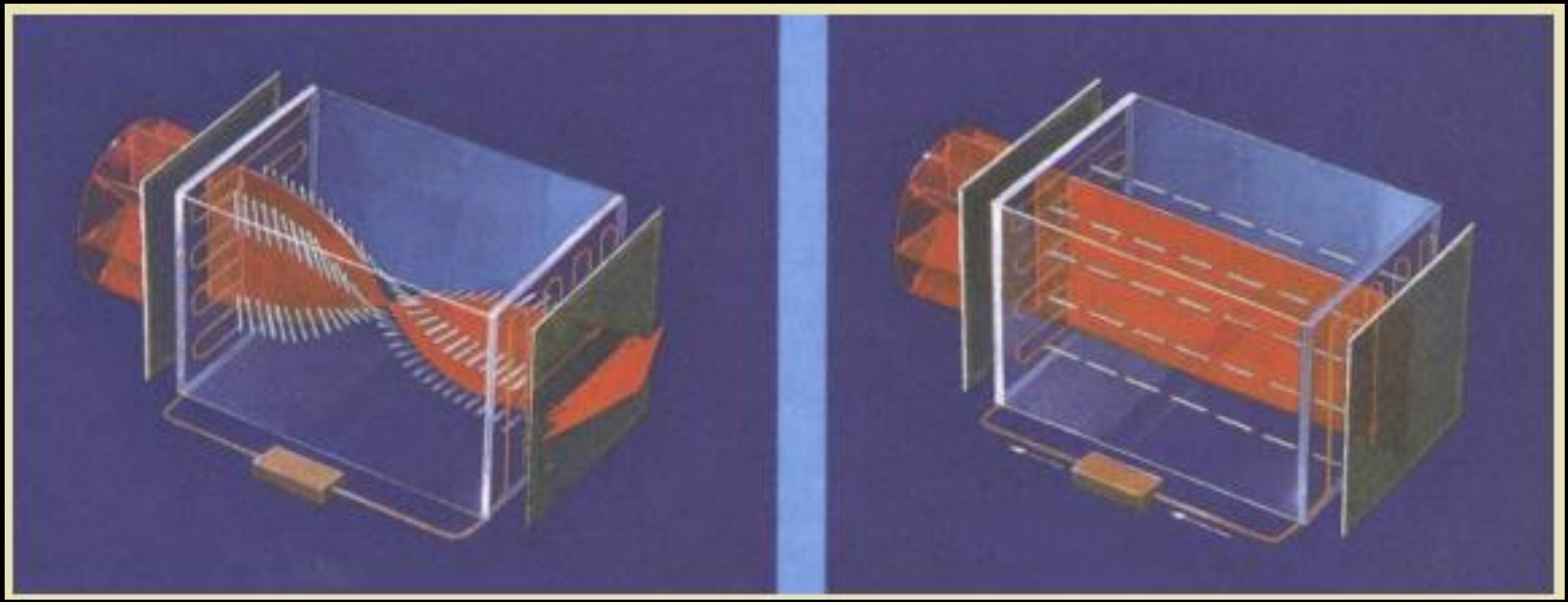
10-4.1 Liquid Crystal - I



Liquid Crystal - II



Liquid Crystal - III



LCD - Liquid Crystal Display