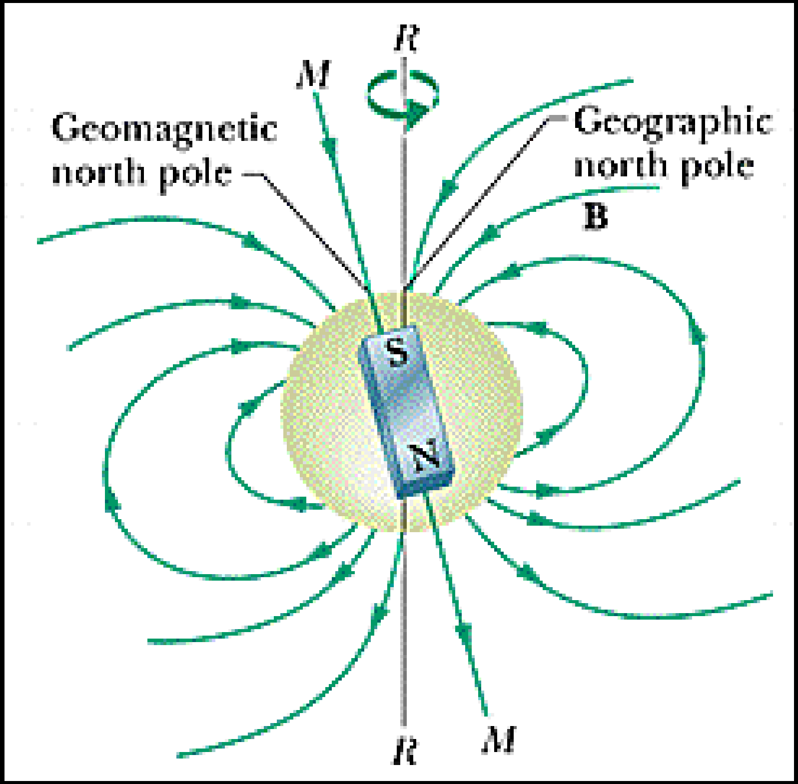
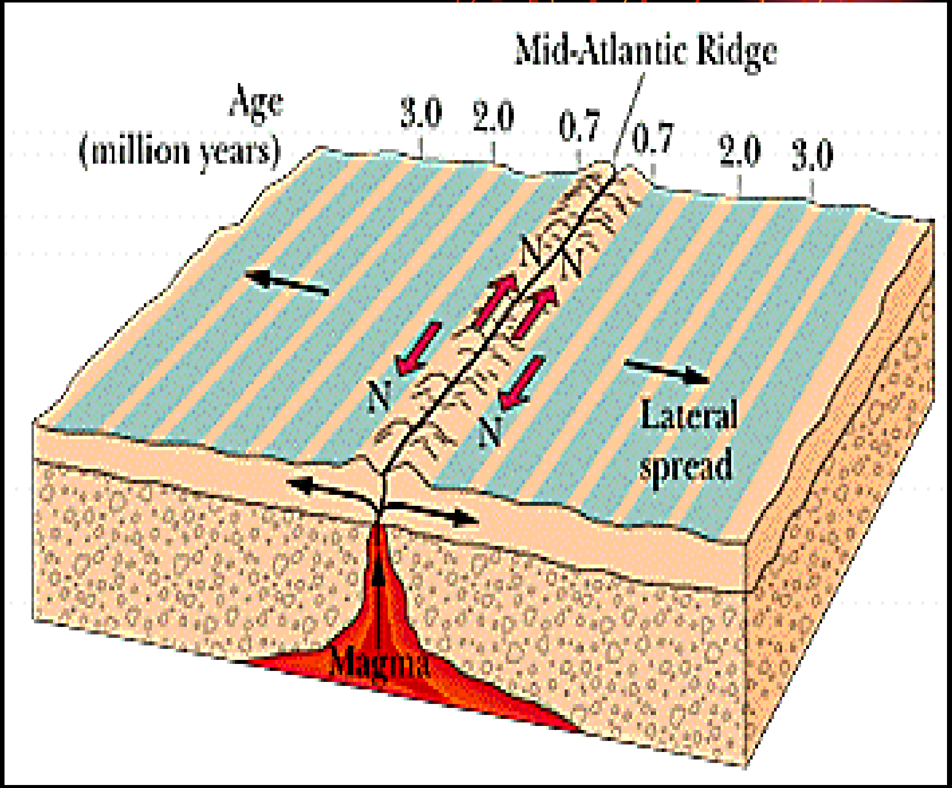
12 Magnetism of Matter 磁性

Electromagnetic Waves 電磁波

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

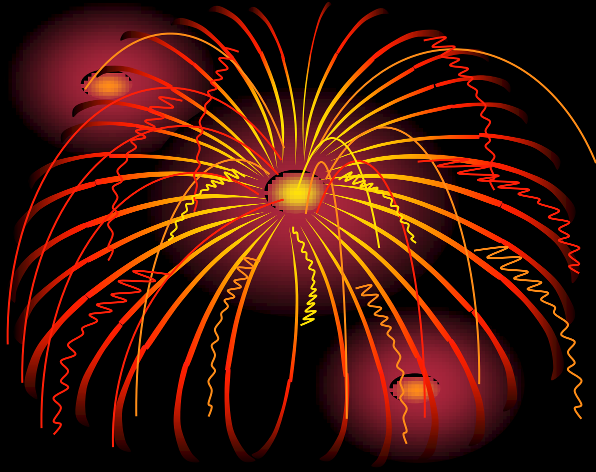
The Magnetic field of the Earth





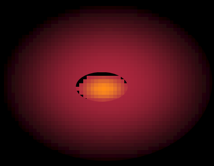
The earth's dipole field

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

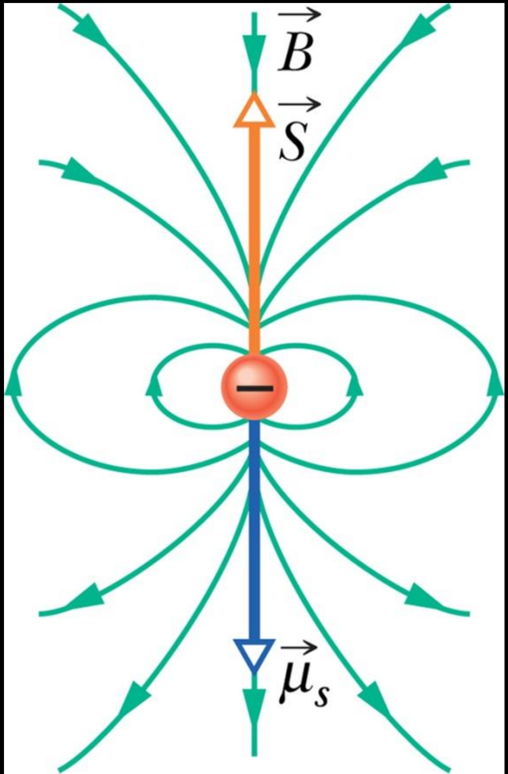


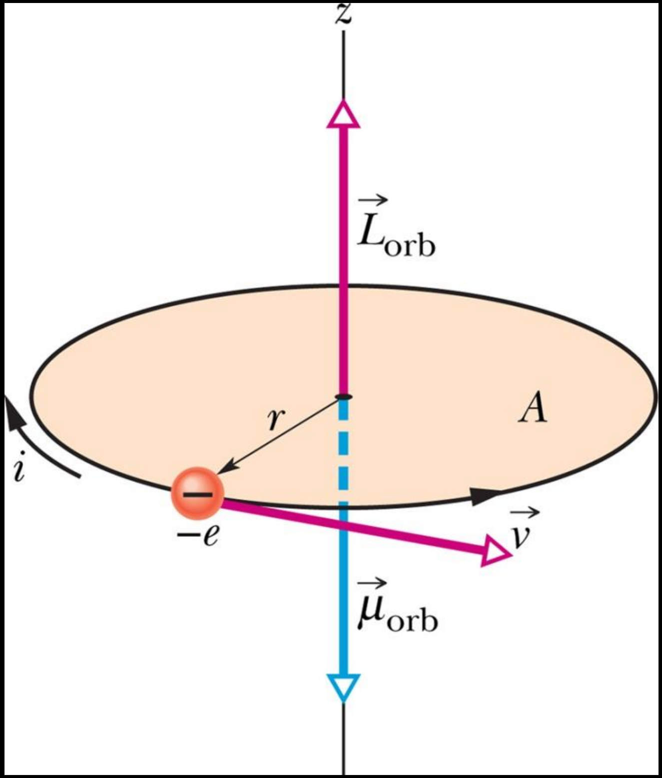
12-1 Magnetic Materials

- 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





Orbital Magnetic Dipole Moment

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

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

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

orbital magnetic quantum number

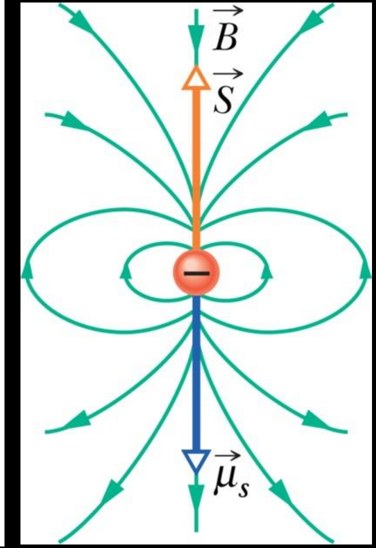
Spin Magnetic Dipole Moment and Bohr magneton

spin magnetic quantum number

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

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

$$\boxed{\mu_{\mathrm{B}}} = \frac{eh}{4\pi m} = 9.27\times10^{-24}\,\mathrm{J/T}$$

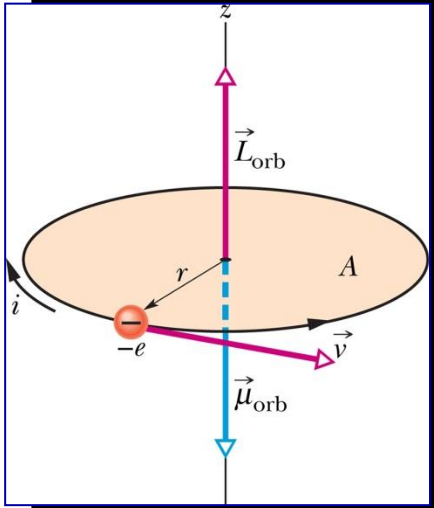


Loop Model for Electron Orbits

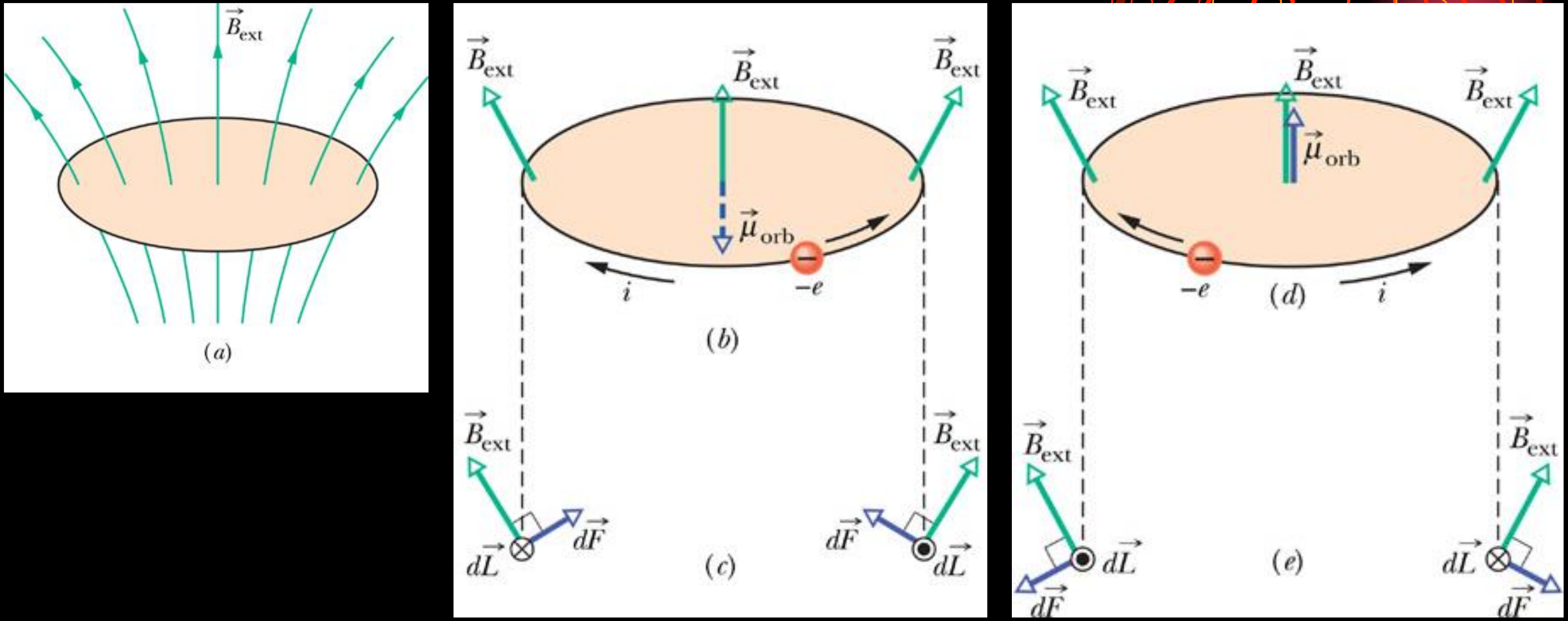
$$\mu_{orb} = iA, i = \frac{\text{charge}}{\text{time}} = \frac{e}{2\pi r / v}$$

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

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



Loop Model in a Nonuniform Field



When B_{ext} is turned on:

downward μ and
upward force
increase

upward μ and
downward force
decrease

Loop Model in a Nonuniform Field

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

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

- permeability 導磁率
- susceptibility 磁化率

$$\mu = K_m \mu_0$$

$$\chi_m = K_m - 1$$

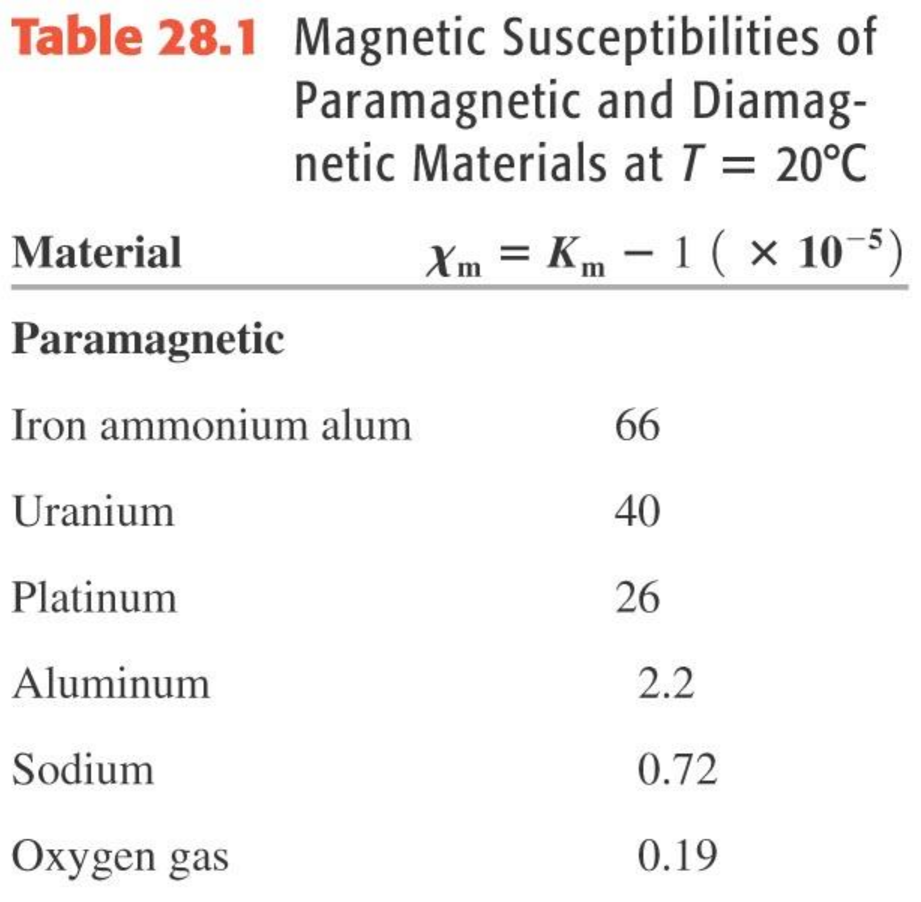
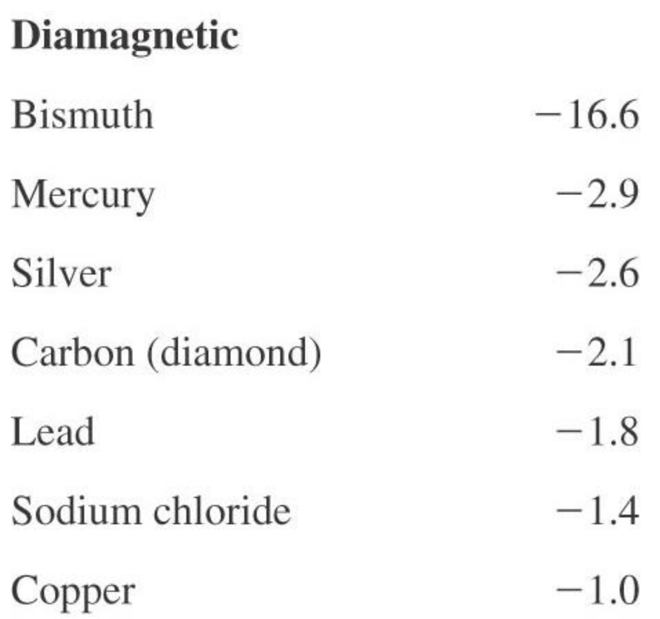



Table 28.1 Magnetic Susceptibilities of Paramagnetic and Diamagnetic Materials at $T = 20°C$

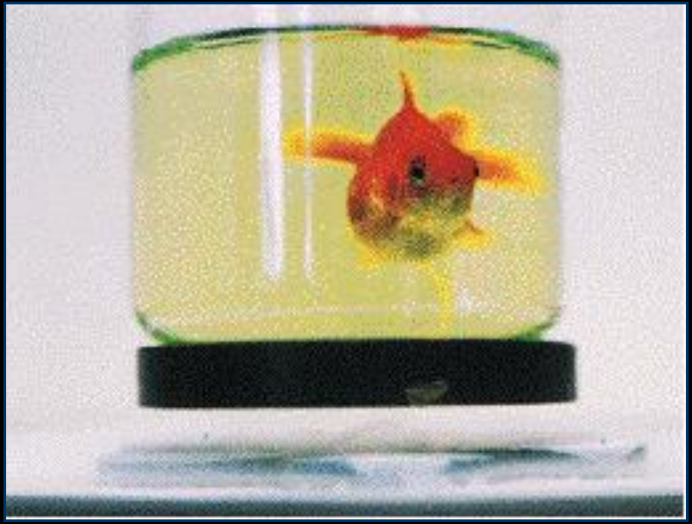
Material	$\chi_m = K_m - 1\ (\times 10^{-5})$
Paramagnetic	
Iron ammonium alum	66
Uranium	40
Platinum	26
Aluminum	2.2
Sodium	0.72
Oxygen gas	0.19
Diamagnetic	
Bismuth	−16.6
Mercury	−2.9
Silver	−2.6
Carbon (diamond)	−2.1
Lead	−1.8
Sodium chloride	−1.4
Copper	−1.0

bismuth铋

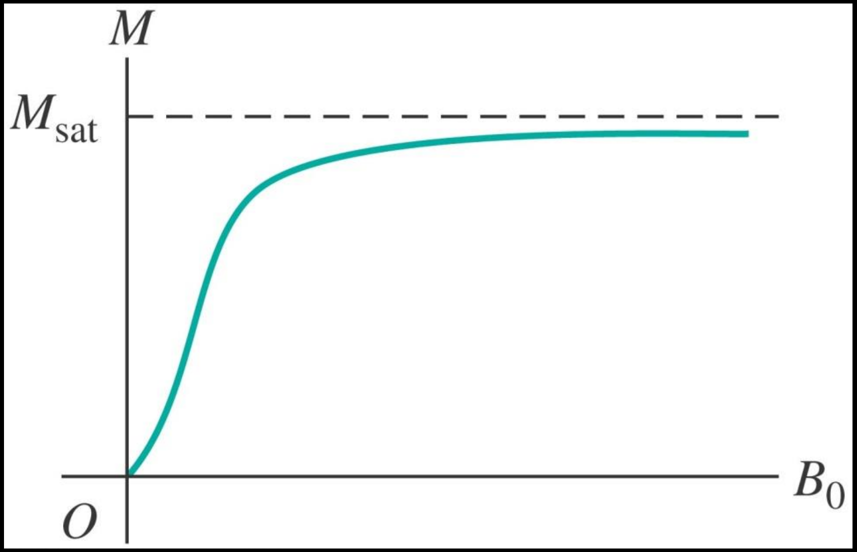
pyrolytic graphite 熱解石墨

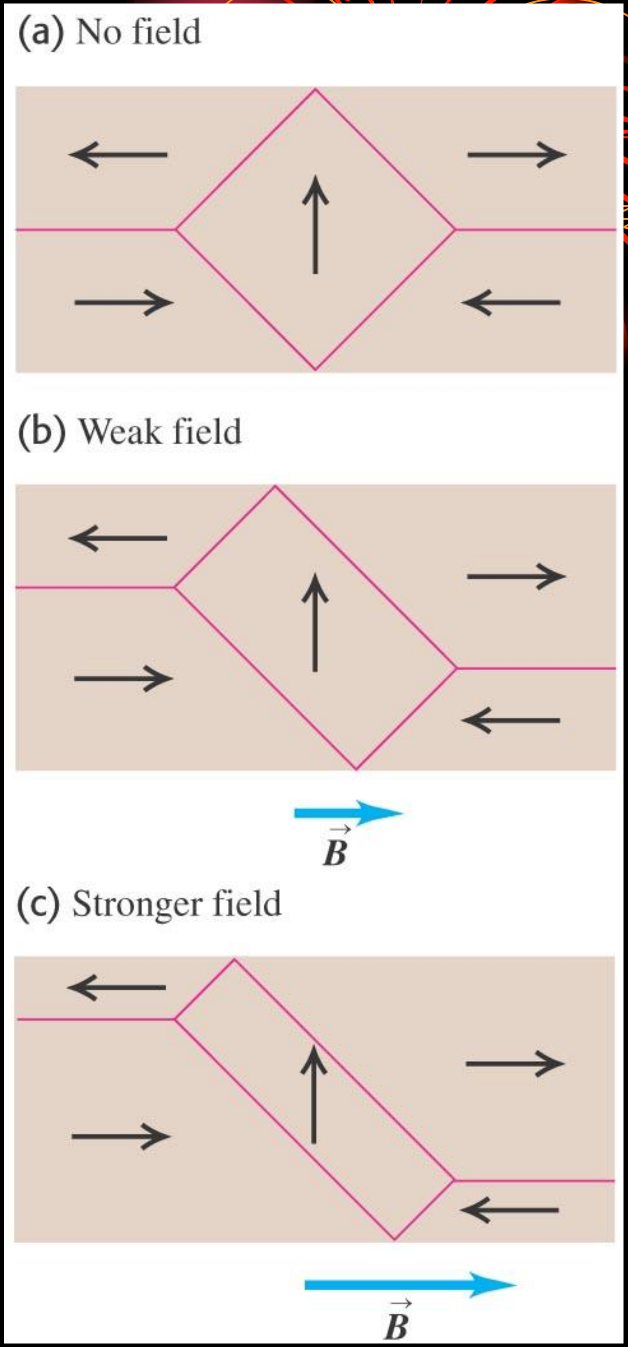
12-1.1 Diamagnetism

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。



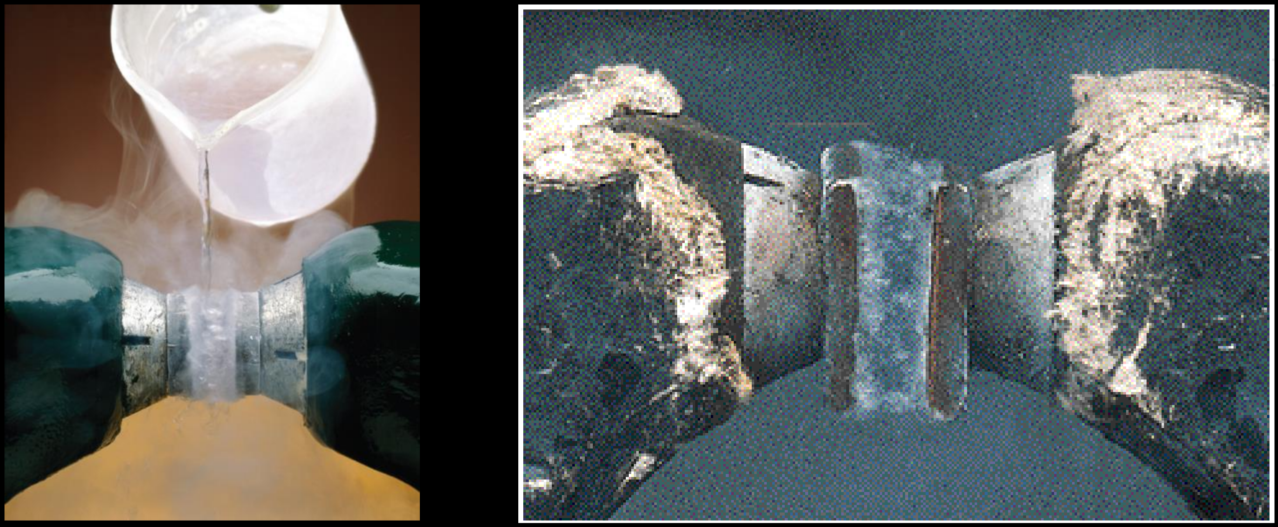
Diamagnetism and ferromagnetism





12-1.2 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。



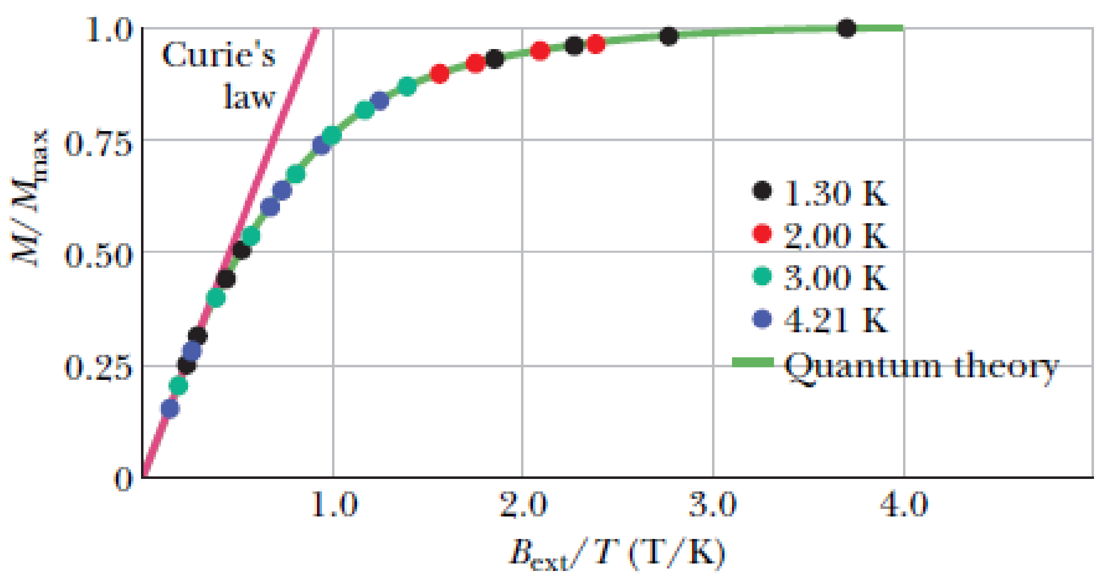
- 液態氧被吸在兩個磁極之间

12-1.2.1 Curie' s Law

M : Magnetization

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

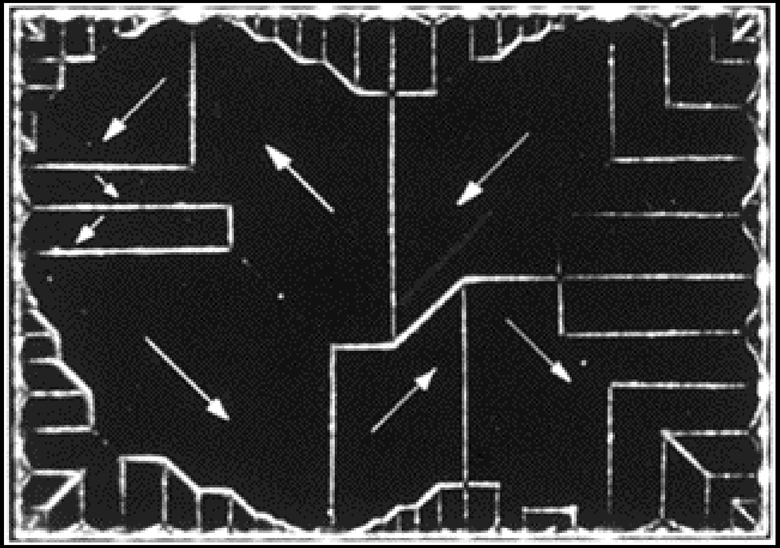
$$M = C\frac{B_{\text{ext}}}{T}$$

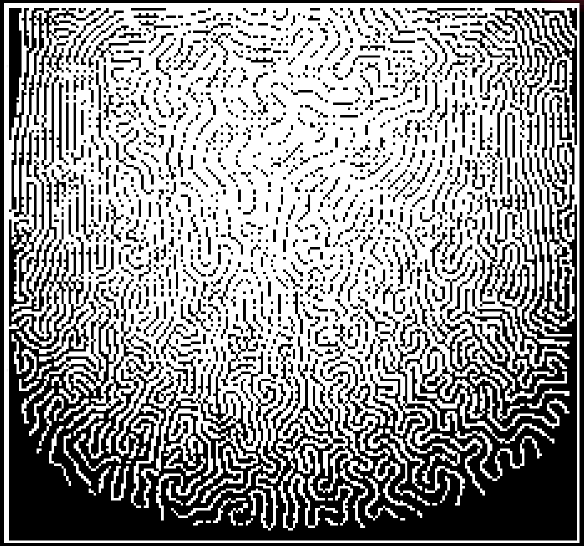


*A magnetization curve for potassium chromium sulfate*硫酸铬钾

12-1.3 Ferromagnetism

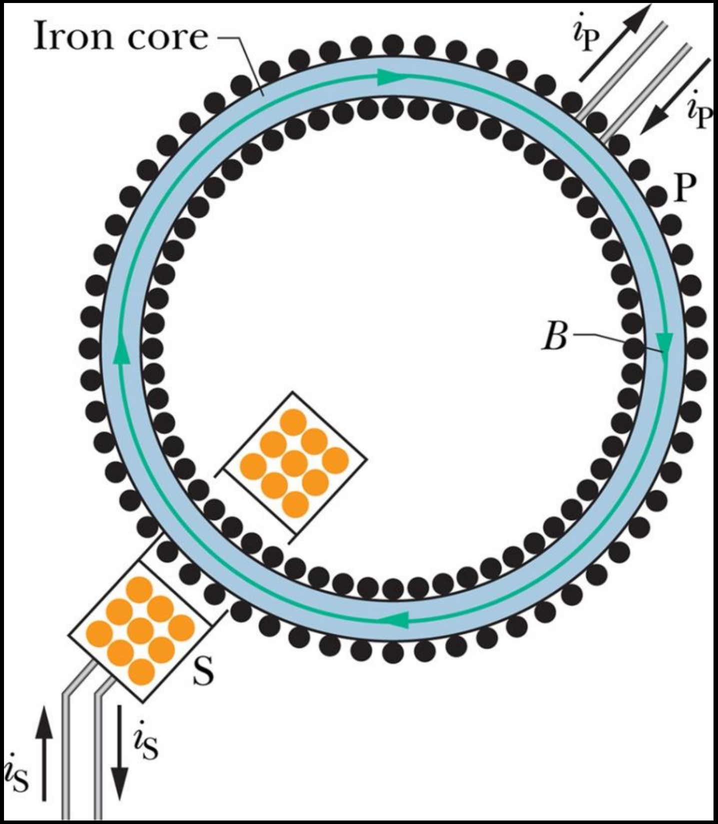
- 鎳的磁域(magnetic domain)





Ferrohydrodynamics

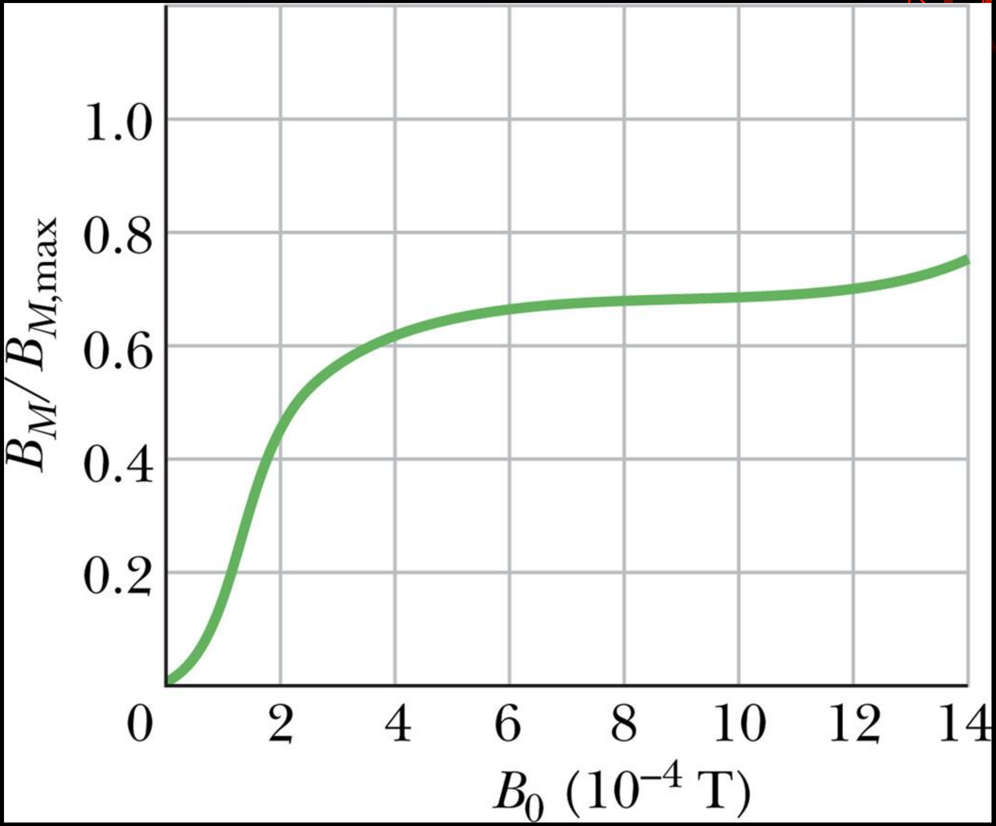
12-1.3.1 Rowland Ring



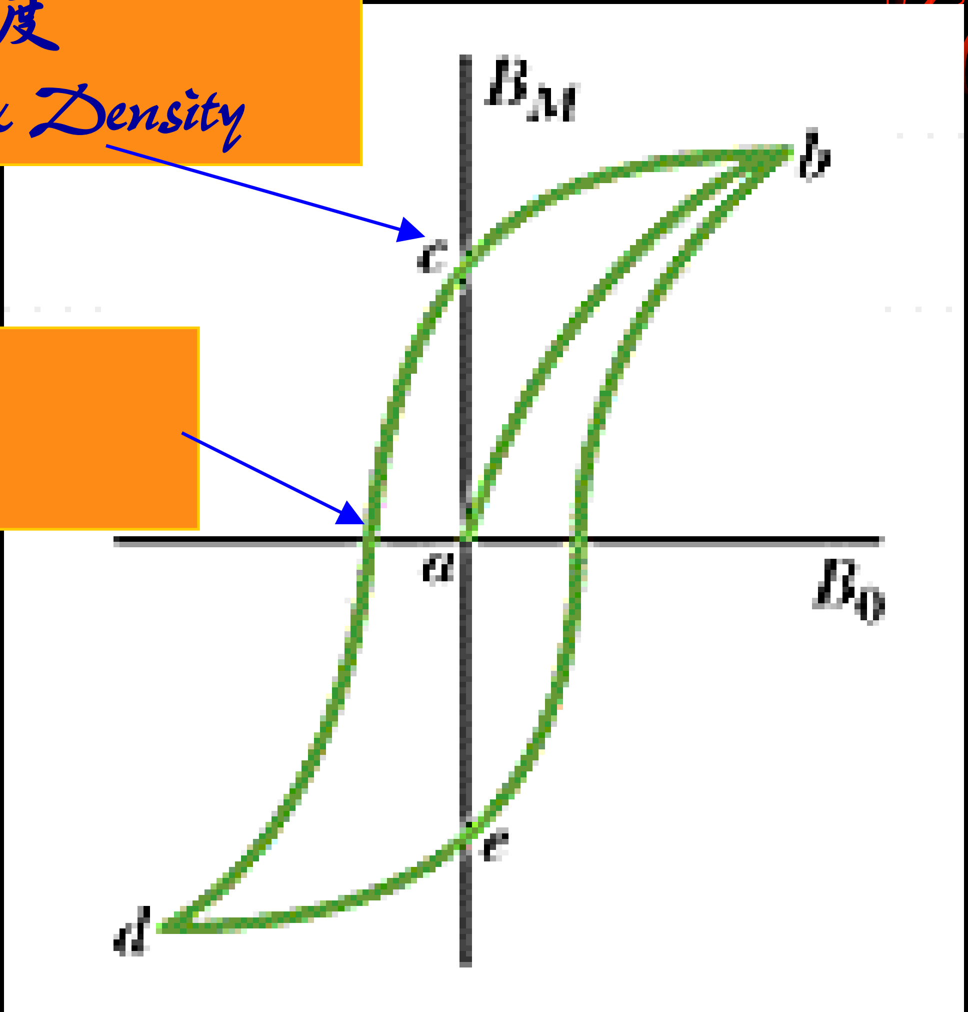
$$B_0 = \mu_0 i_P n$$

$$B = B_0 + B_M$$

12-1.3.2 Magnetization Curve



12-1.3.3 Hysteresis (磁滯)



殘餘磁通密度

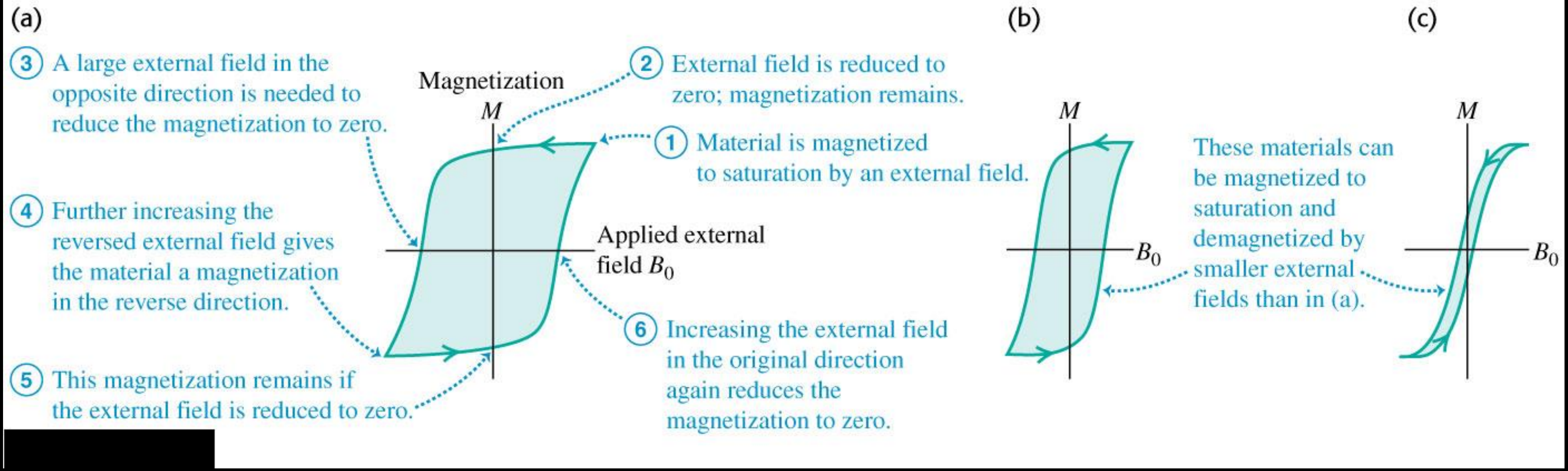
Residual Flux Density

矯頑磁力

coercive force

Hysteresis

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



① Material is magnetized to saturation by an external field.

② External field is reduced to zero; magnetization remains.

③ A large external field in the opposite direction is needed to reduce the magnetization to zero.

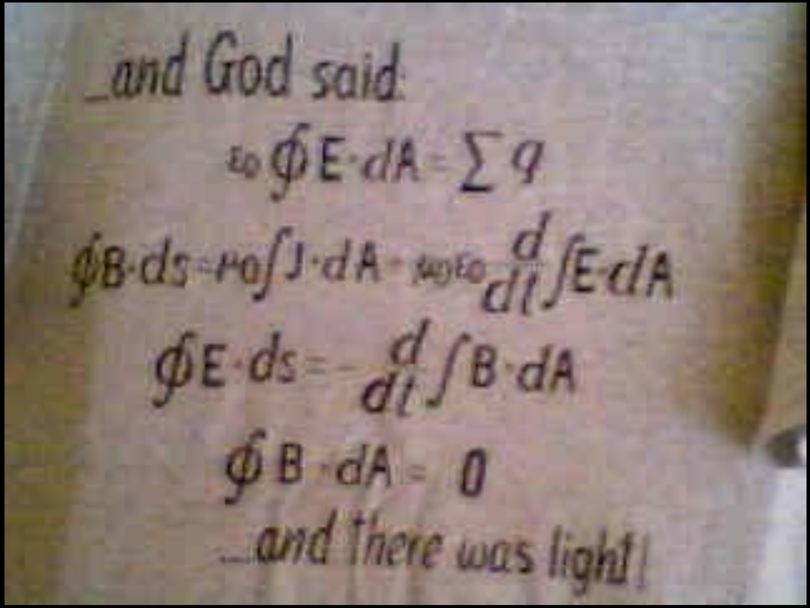
④ Further increasing the reversed external field gives the material a magnetization in the reverse direction.

⑤ This magnetization remains if the external field is reduced to zero.

⑥ Increasing the external field in the original direction again reduces the magnetization to zero.

These materials can be magnetized to saturation and demagnetized by smaller external fields than in (a).

12-2 Maxwell’ s Equations



_and God said:

$$\varepsilon_0 \oint E \cdot dA = \sum q$$

$$\oint B \cdot ds = \mu_0 \int J \cdot dA + \mu_0 \varepsilon_0 \frac{d}{dt} \int E \cdot dA$$

$$\oint E \cdot ds = -\frac{d}{dt} \int B \cdot dA$$

$$\oint B \cdot dA = 0$$

...and there was light!

$$\nabla \cdot B = 0$$

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

$$\nabla \cdot D = \rho$$

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

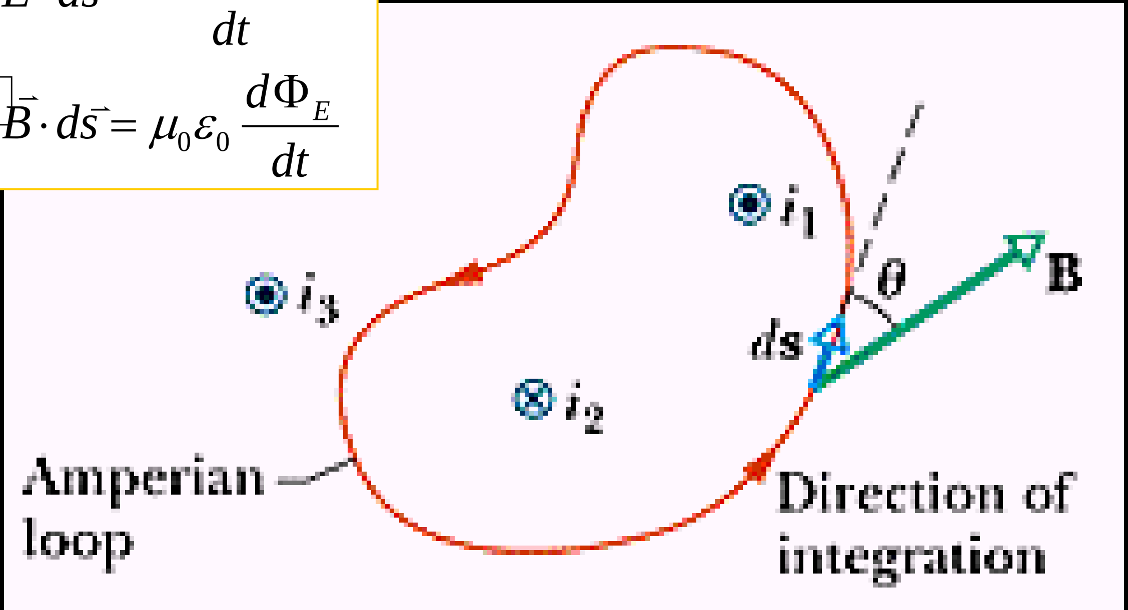
12-2.1 線積分與面積分 (安培迴路和高斯面)

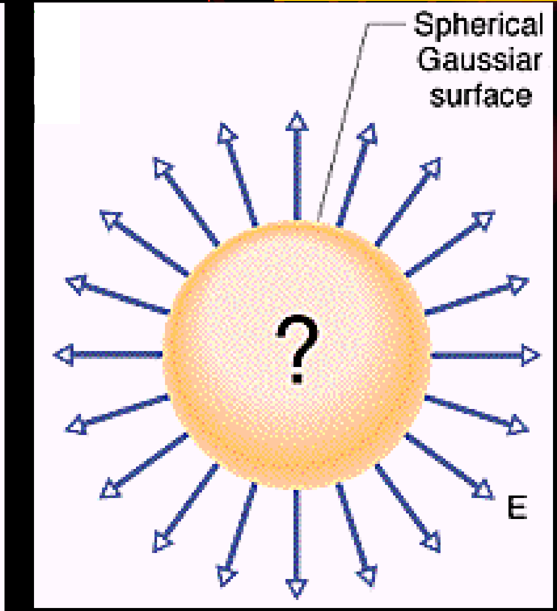
$$\oint \vec{E}\cdot d\vec{s} = -\frac{d\Phi_B}{dt}$$

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

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

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

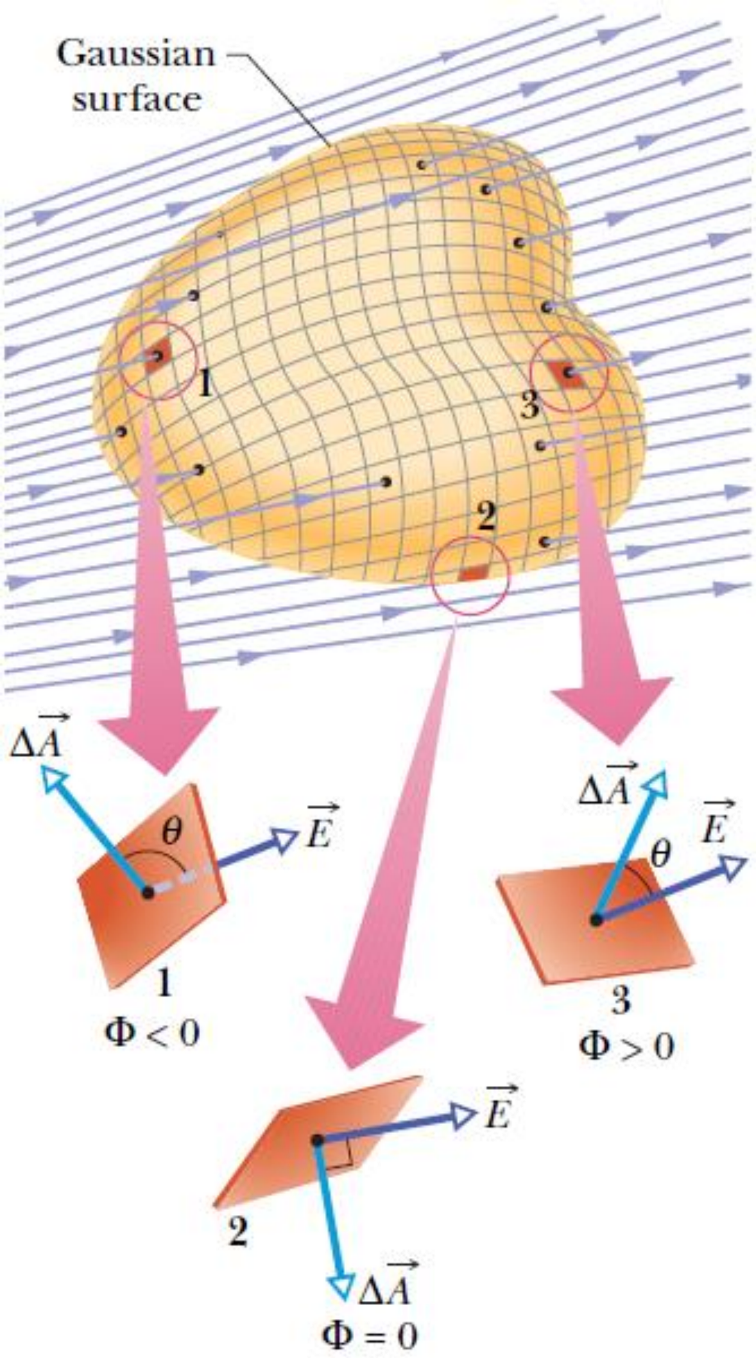


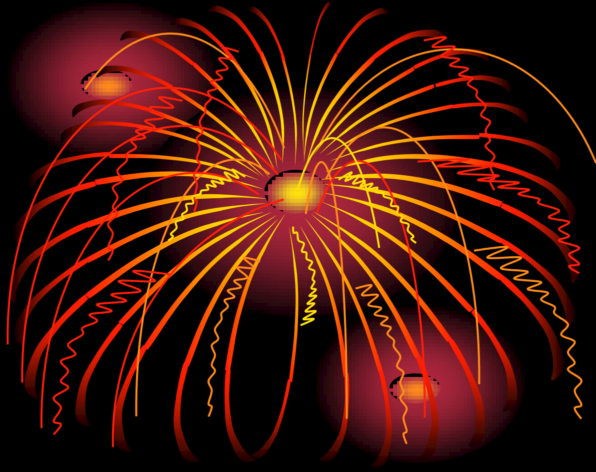


磁場環流量 (安培定律)　　電場通量

電場環流量 **法拉第定律** 磁場通量

高斯面





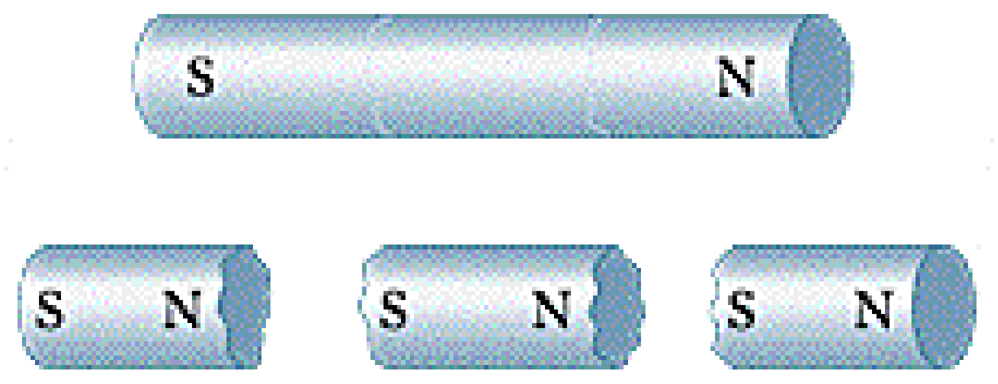
$$\Phi_B = \oint \vec{B} \cdot d\vec{A} = 0$$

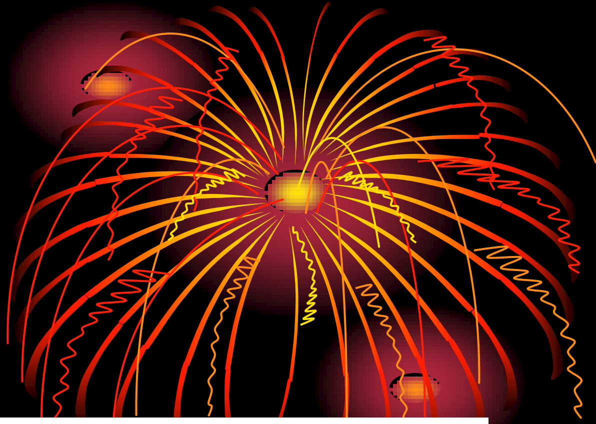
$$\Phi_E = \oint \vec{E} \cdot d\vec{A} = q / \varepsilon_0$$

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

12-2.2 Magnets and magnetic flux (磁鐵和磁通量)

Magnetic <u>dipole</u>: north/south pole



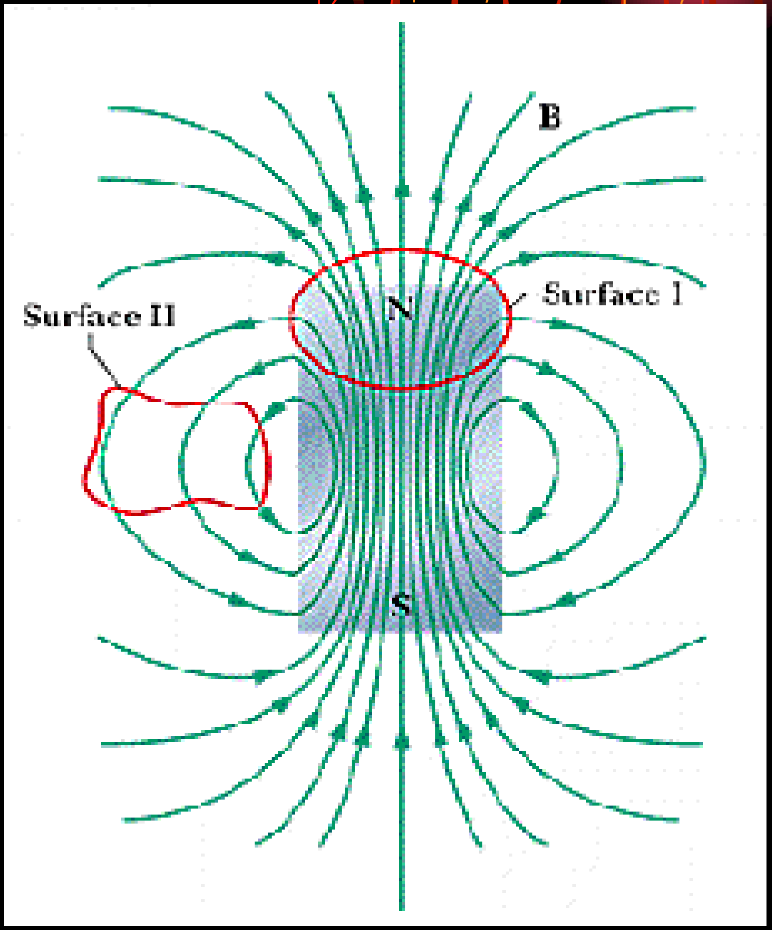


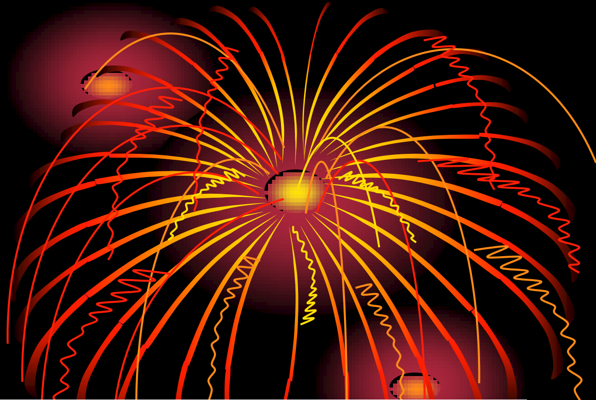
12-2.3 Gauss' Law for Magnetic Fields

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

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

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





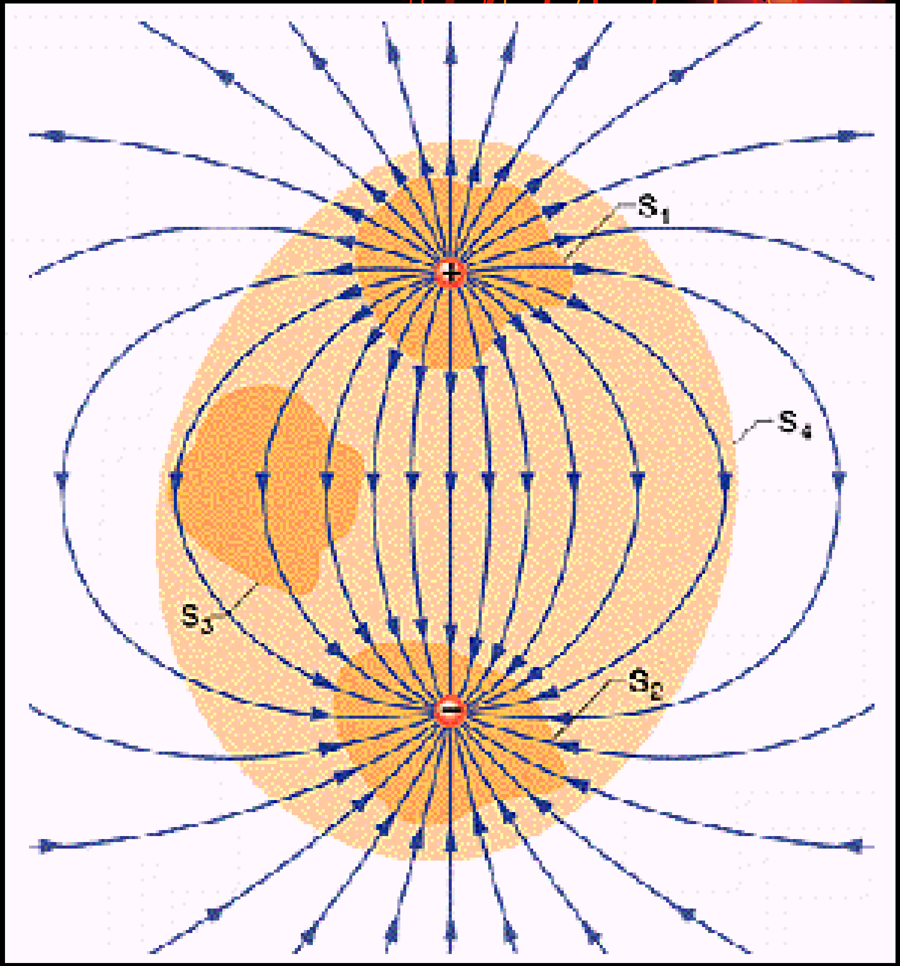
12-2.4 Gauss' Law for electric Fields

Flux ↔ enclosed charge

$$\varepsilon_0 \Phi$$

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

$$= q_{enc}$$



12-2.5 Induced Magnetic Fields

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

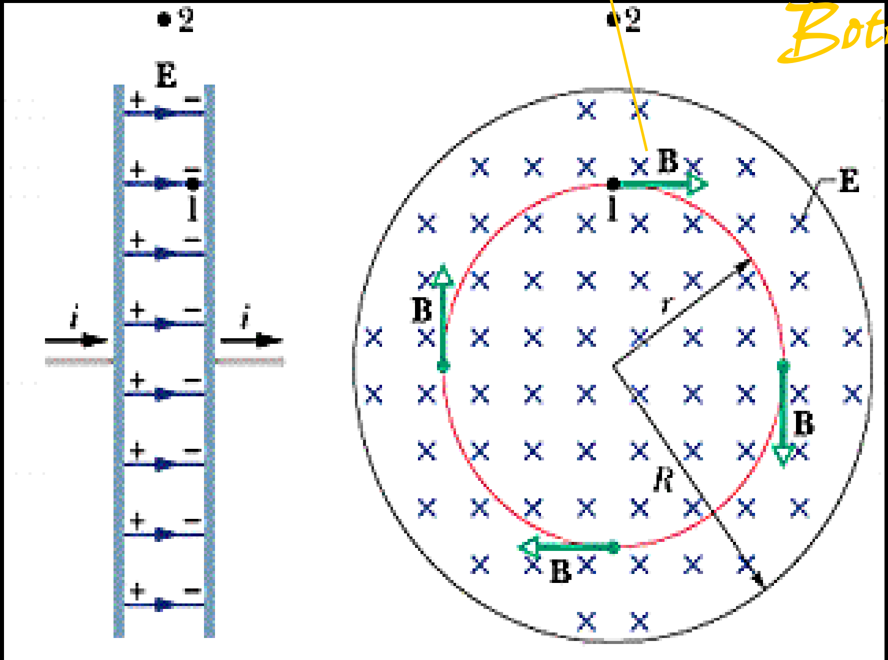
$$\oint \vec{B} \cdot d\vec{s} = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt} \qquad \text{(Maxwell's Law of inductin)}$$

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

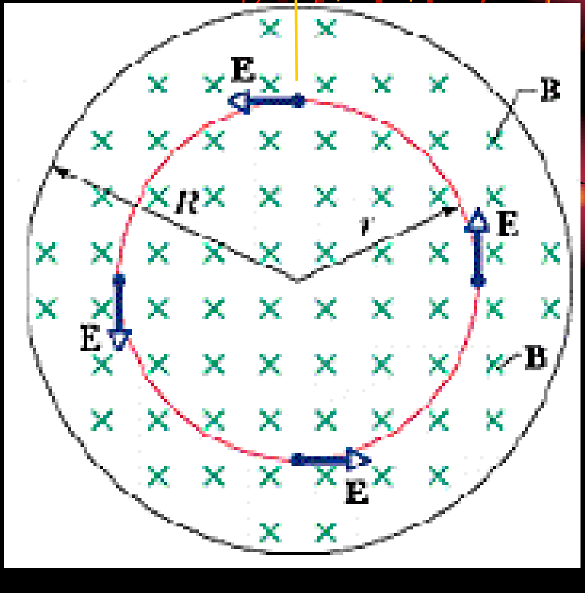
induced B field

induced E field

12-2.6 Ampere-Maxwell Law



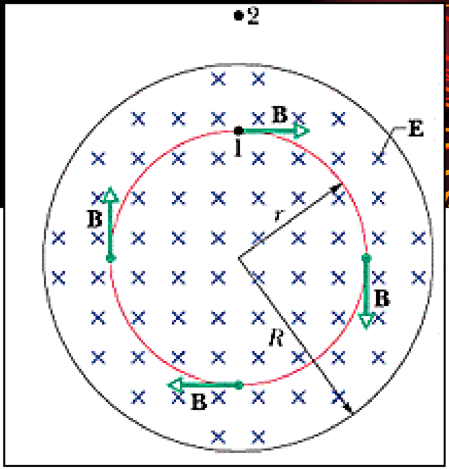
Both increasing



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

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

12-2.7 Find B(r)



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

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

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

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

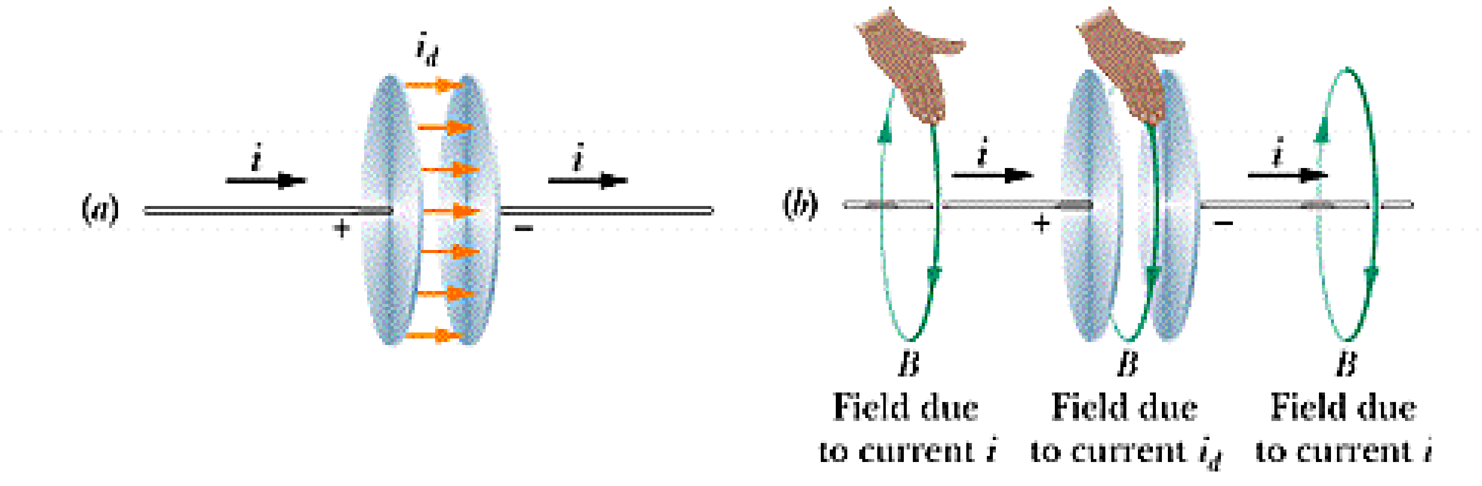
$$B = \frac{\mu_0\varepsilon_0 R^2}{2r}\frac{dE}{dt} \qquad (\text{for } r \ge R)$$

12-2.8 Displacement Current

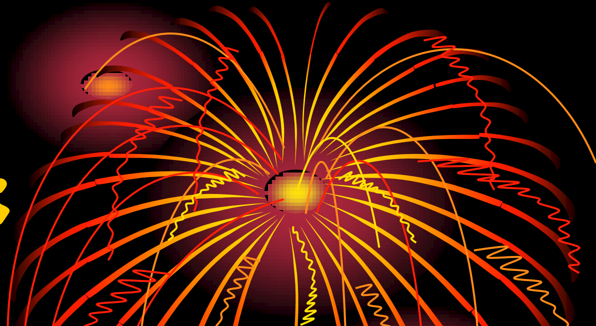
$$\oint \vec{B} \cdot d\vec{s} = \underline{\mu_0 \varepsilon_0 \frac{d\Phi_E}{dt}} + \mu_0 i_{enc}$$

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

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



12-2.9 Maxwell's Equations



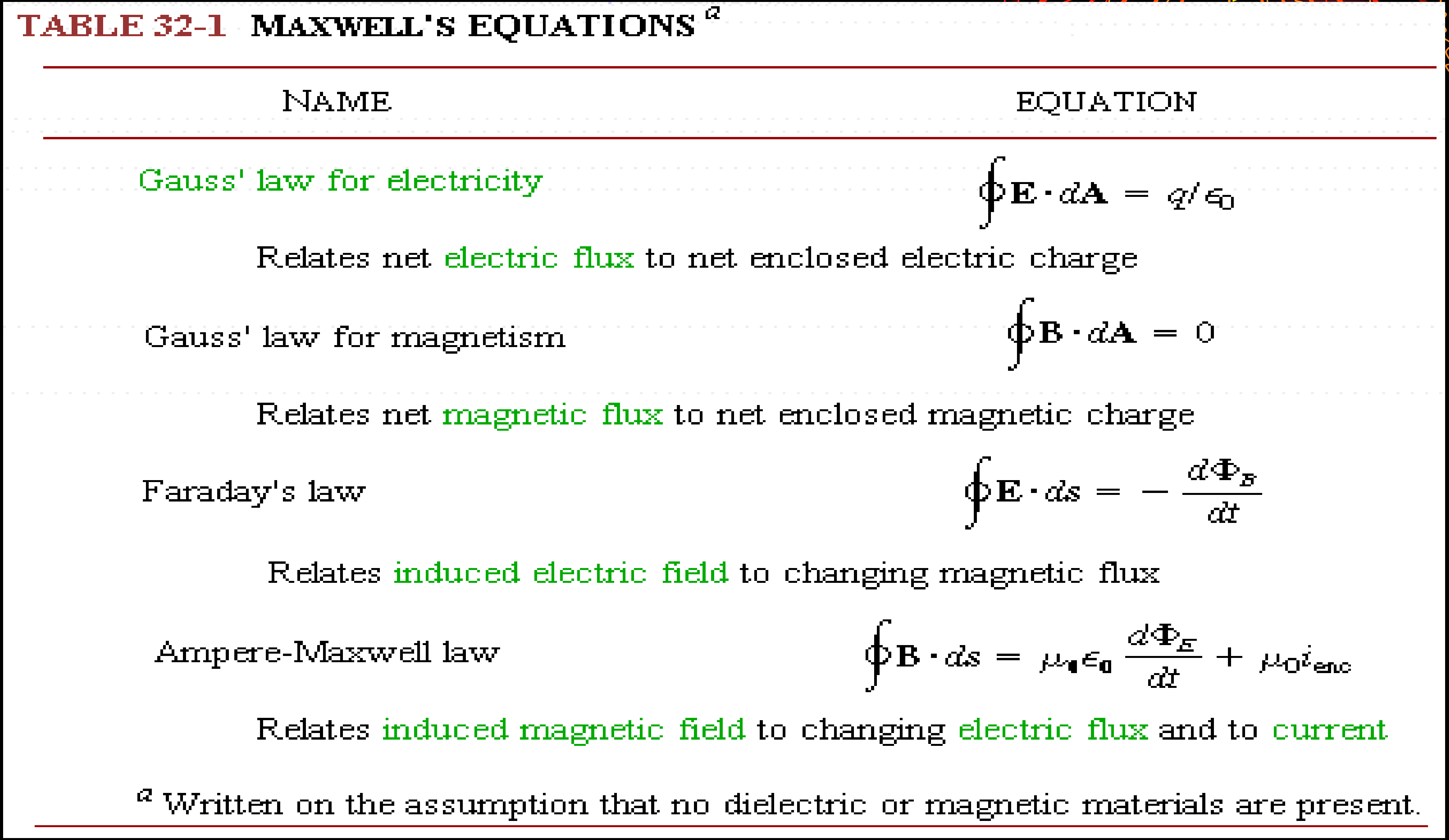


TABLE 32-1 MAXWELL'S EQUATIONS [a]

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	

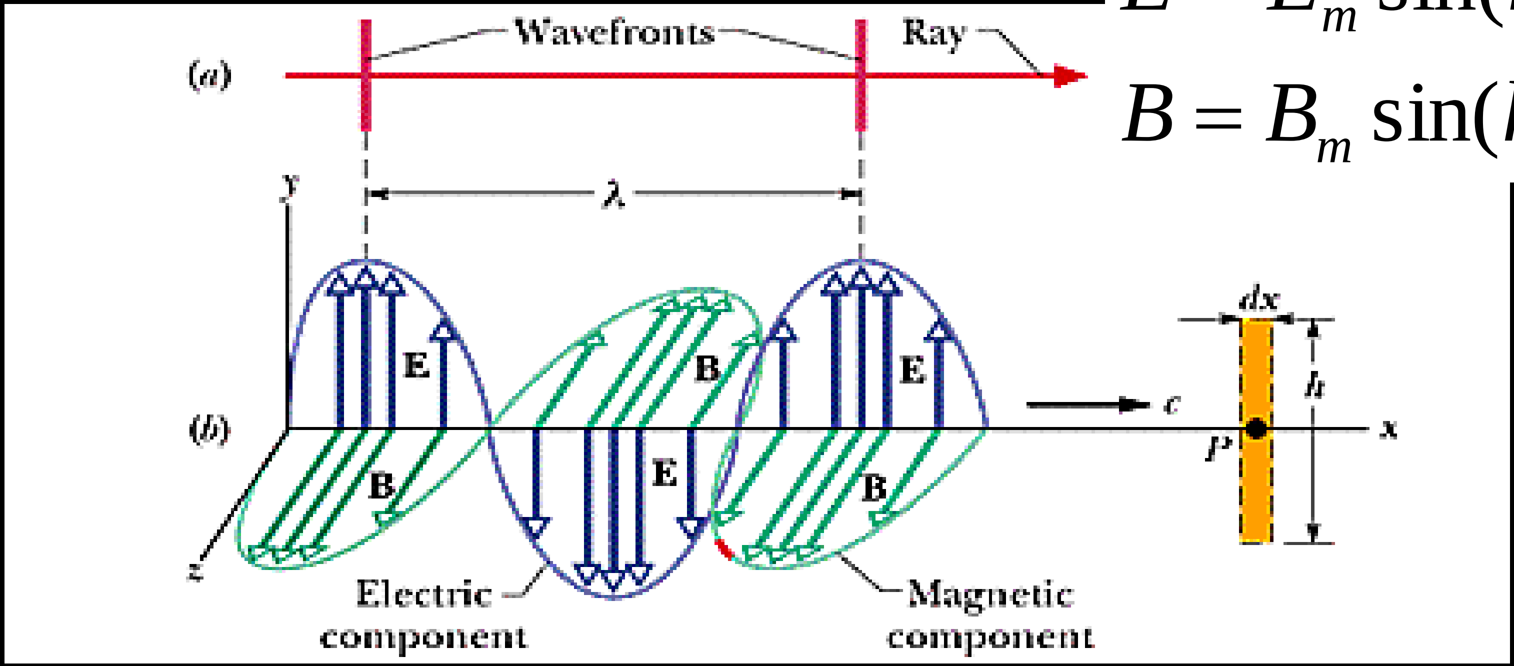
[a] Written on the assumption that no dielectric or magnetic materials are present.

12-3 Electromagnetic Waves

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

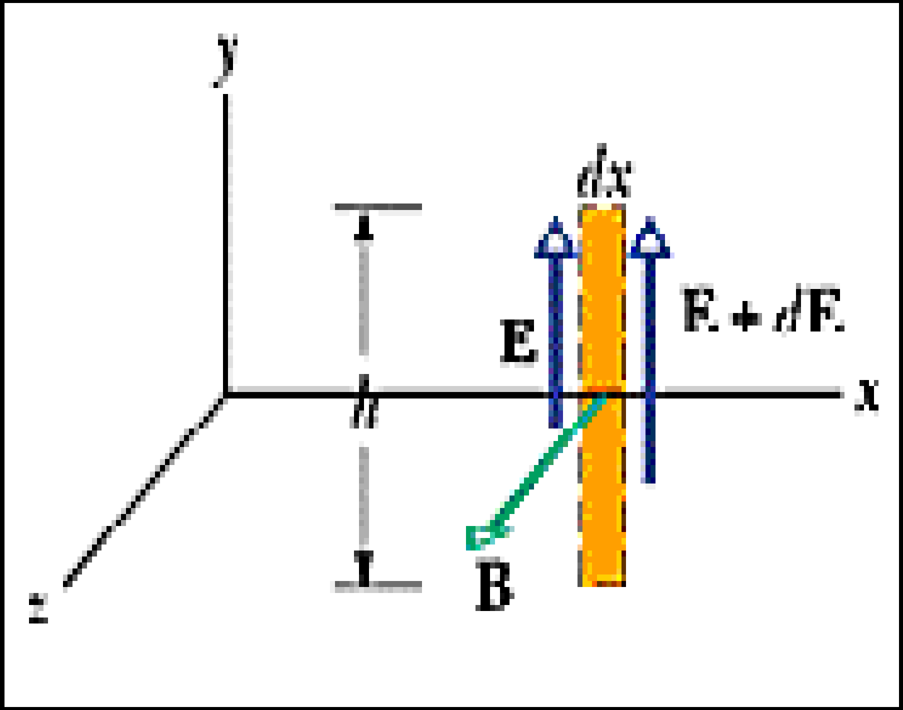
$$E = E_m \sin(kx - \omega t)$$

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



The Traveling Electromagnetic Wave

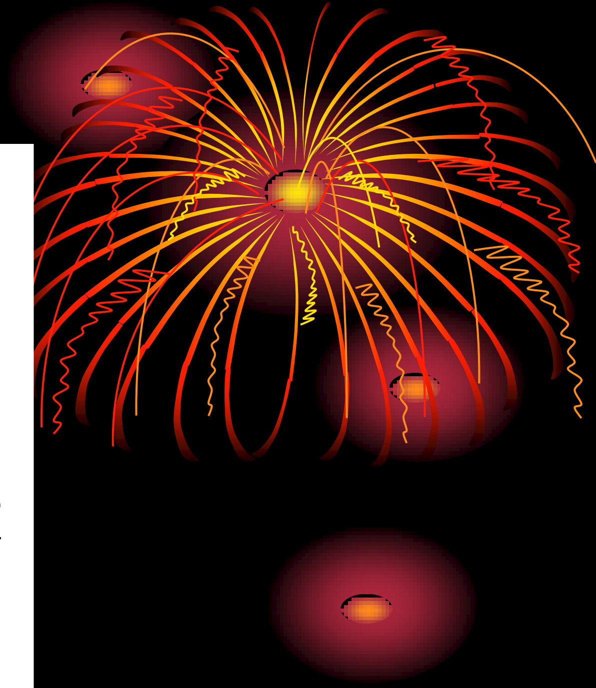
- The induced electric field:



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

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

$$= hdE$$



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

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

$$= hdE$$

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

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

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

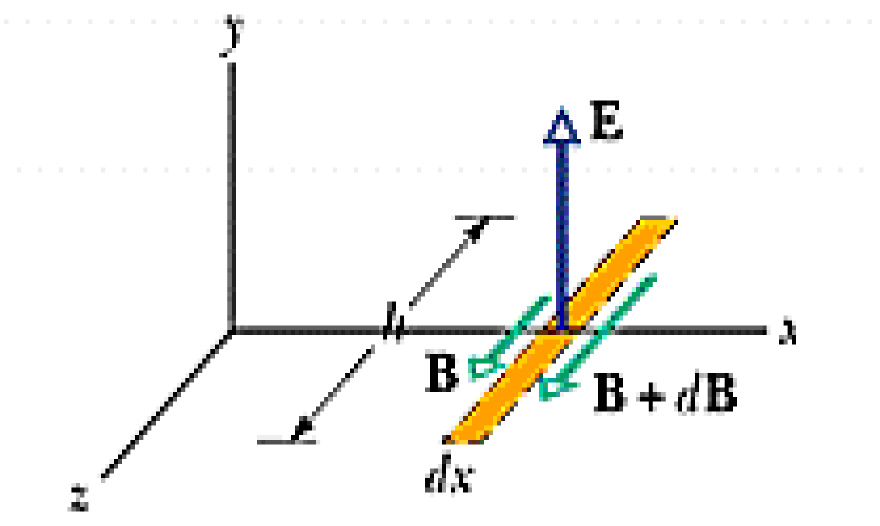
$$\frac{\partial E}{\partial x} = kE_m \cos(kx - \omega t)$$

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

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

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

- The induced magnetic field:



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

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

$$= -hdB$$

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

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

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

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

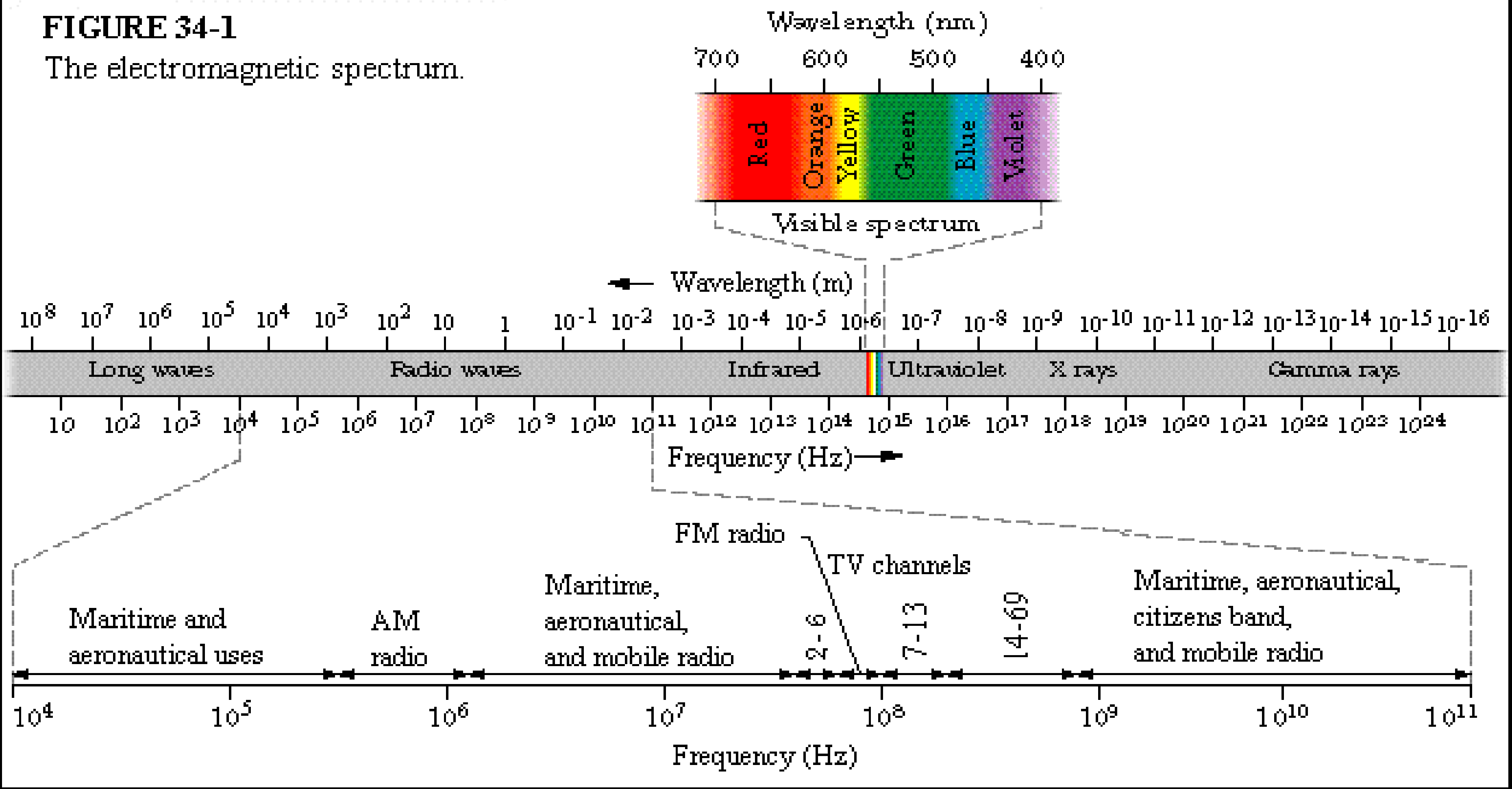
12-3.1 Characteristics

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

430nm - 690nm

12-3.2 Maxwell’s Rainbow

FIGURE 34-1
The electromagnetic spectrum.



12-3.3 Comets

What shapes the curved dust tail of a comet?

12-3.3.1 Radiation Pressure

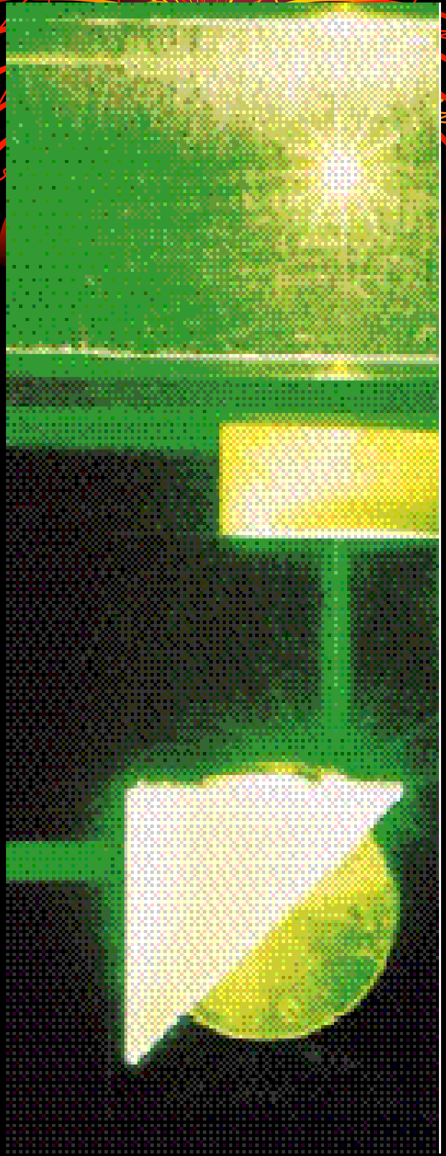
- Momentum Gain of an Object

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

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

Momentum change

energy change

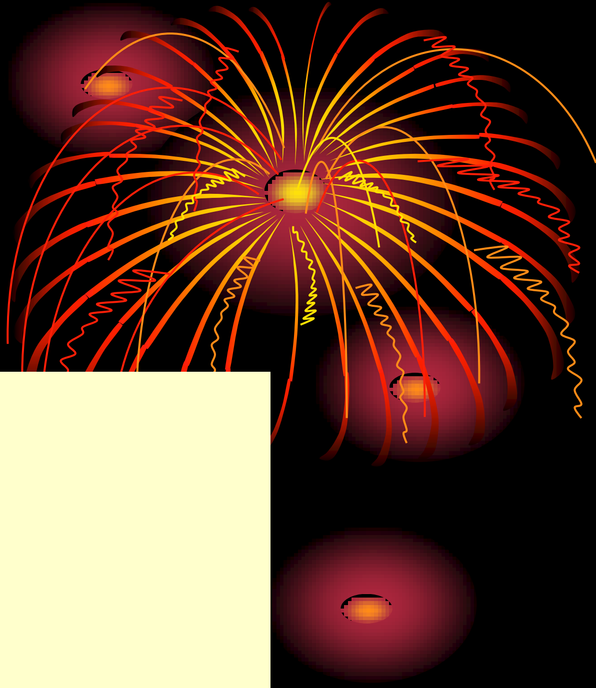


The Force Exerted by Radiation

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

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

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



• The size of comet particles

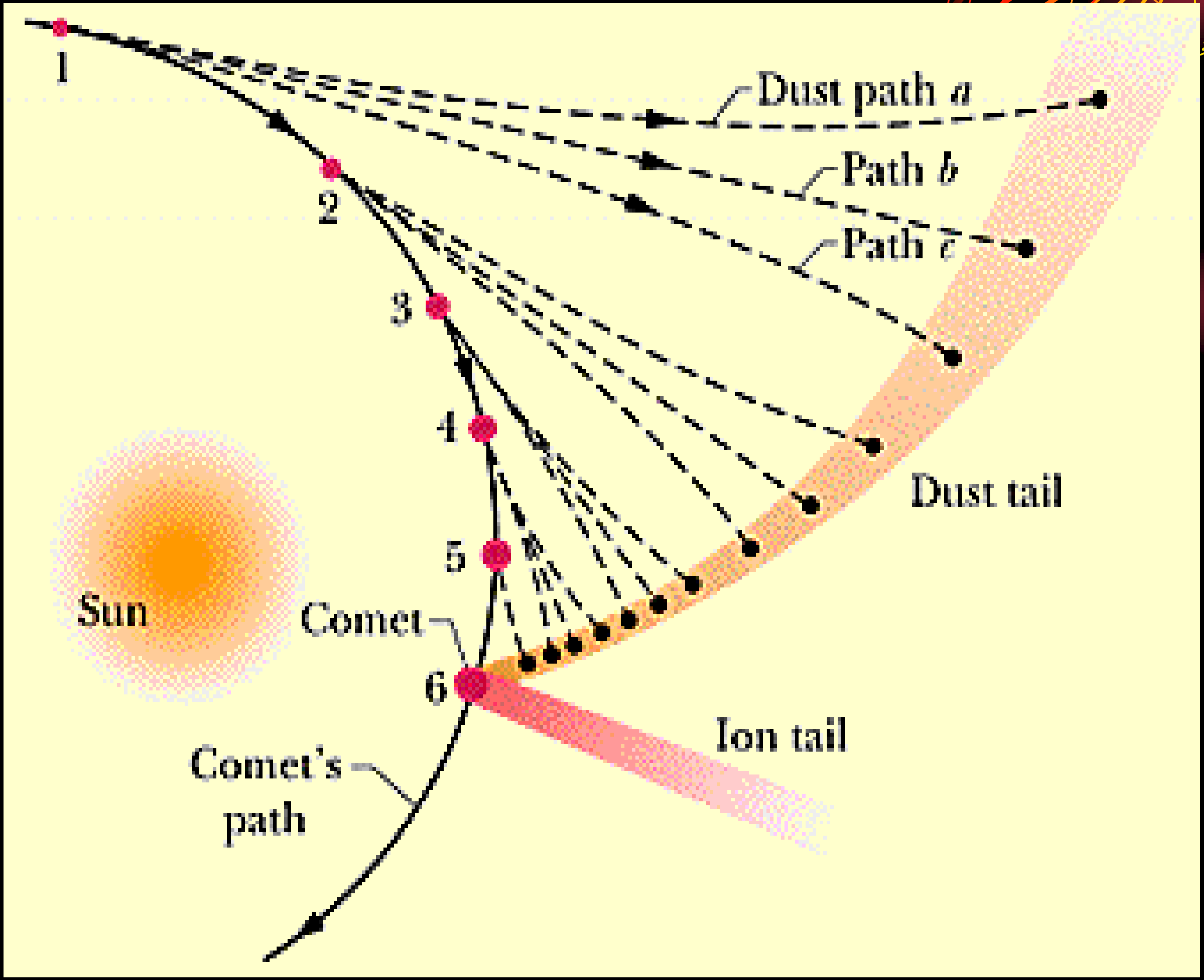
$$I = \frac{P_S}{4\pi r^2} \qquad F_r = \frac{IA}{c}$$

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

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

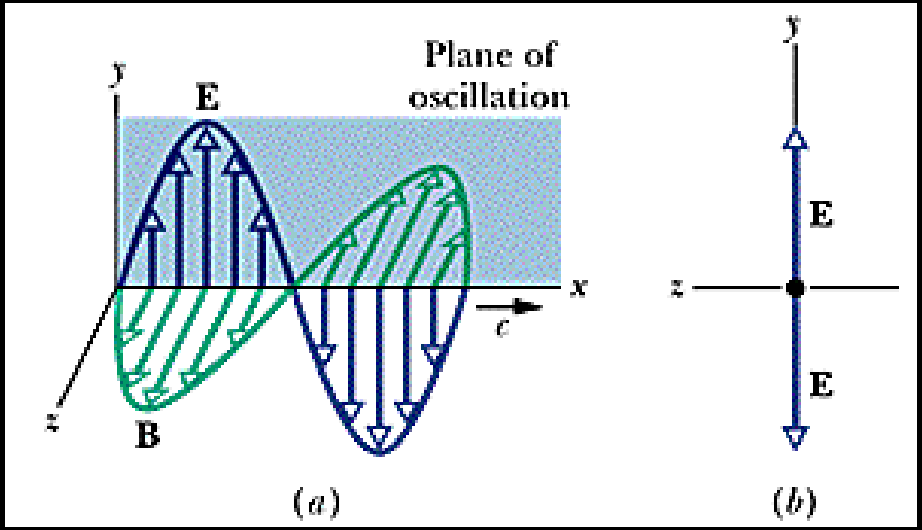
$$F_r = F_g \rightarrow R = \frac{3P_S}{16\pi c\rho GM_S} = 1.7\times 10^{-7}\, m$$

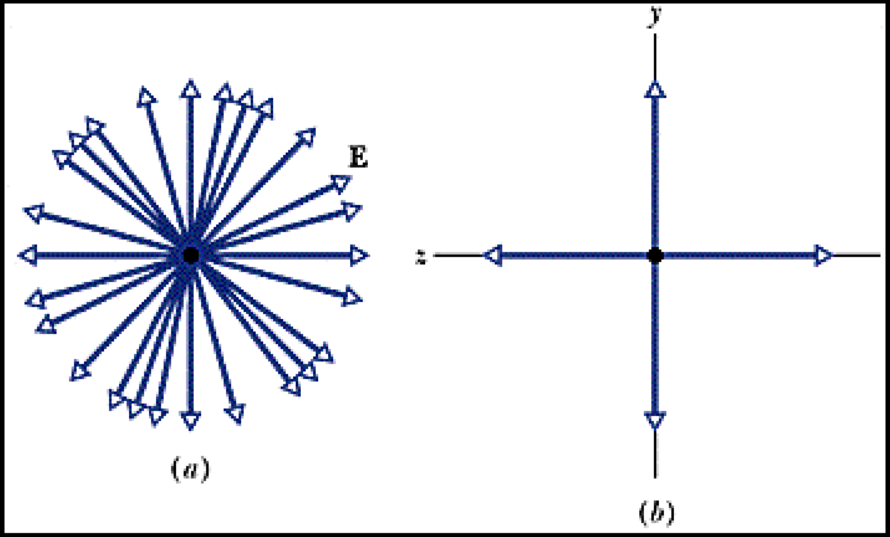
光壓 αR^2 重力 αR^3



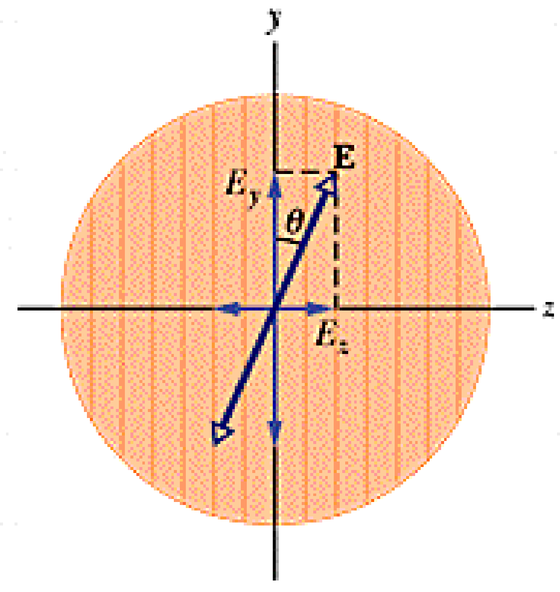
12-4 Polarization (偏振)

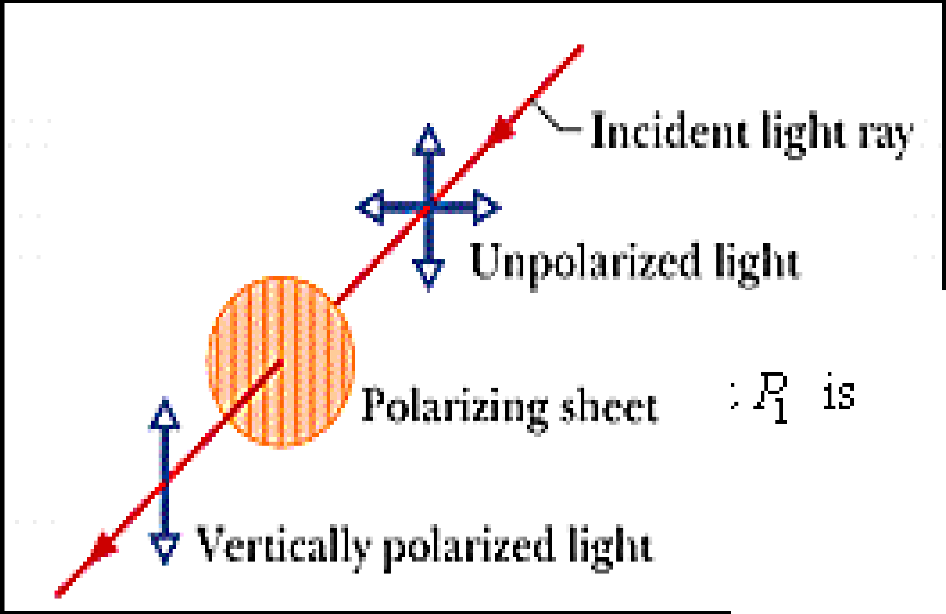
- Polarized Light
- The Plane of Polarization
- Linear, Circular and Elliptical polarization



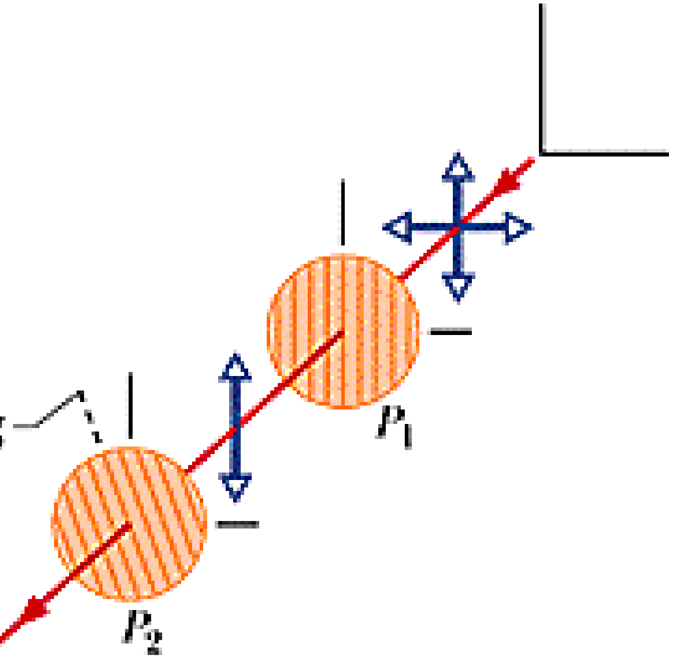


偏振片

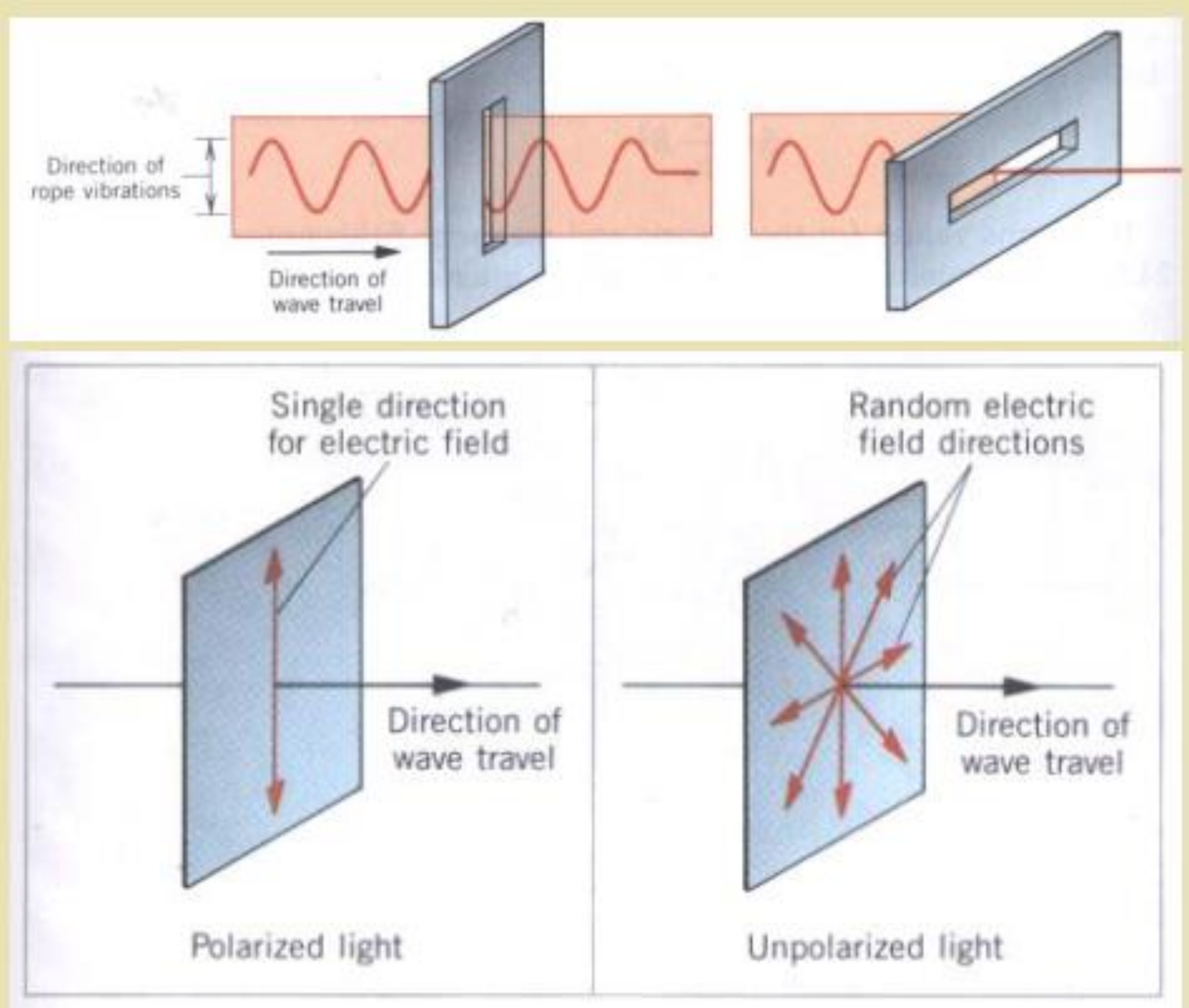

y
E
E_y
θ
z
E_z


Incident light ray
Unpolarized light
Polarizing sheet
Vertically polarized light

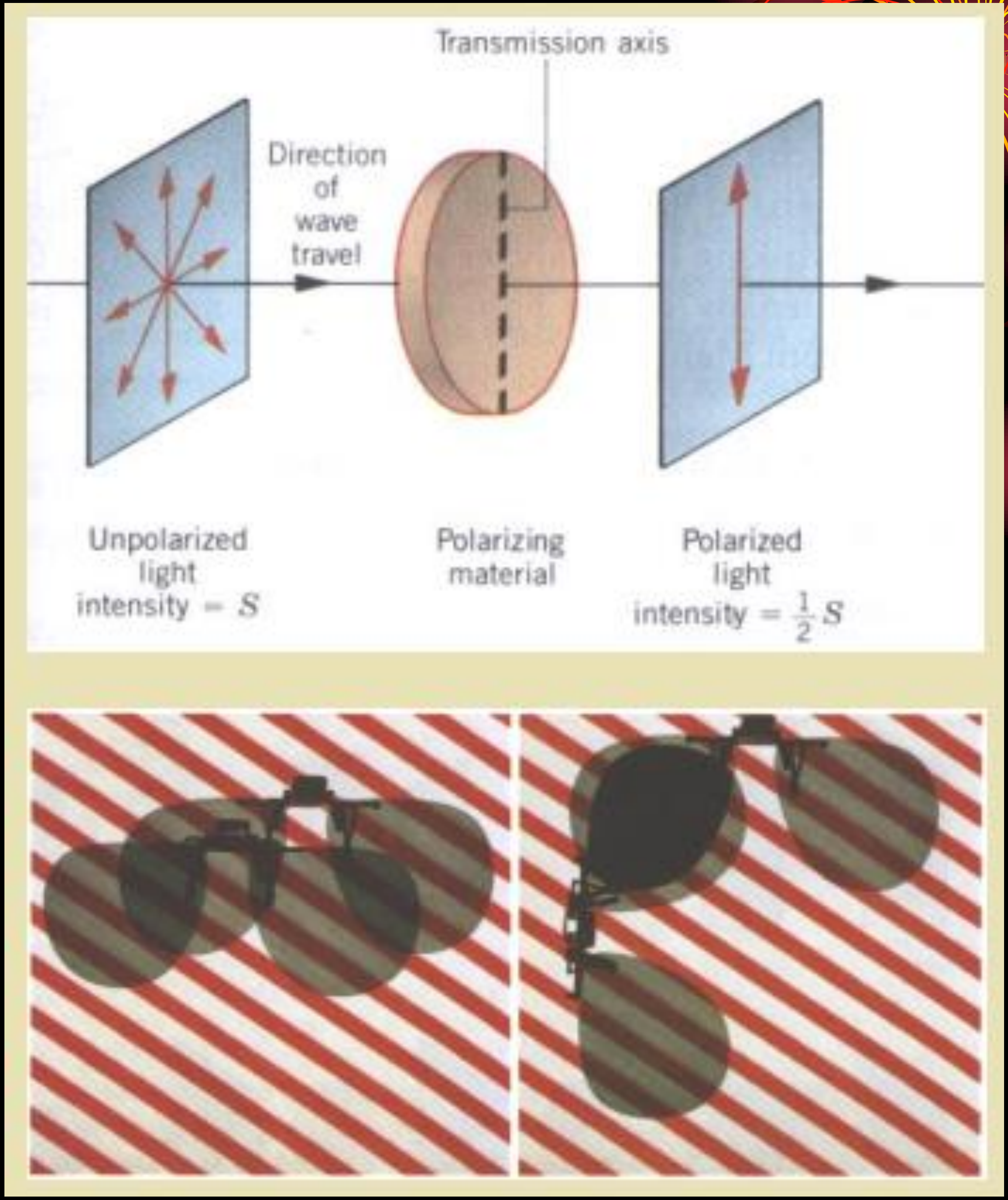
: P_1 is


Polarizing direction
P_1
P_2

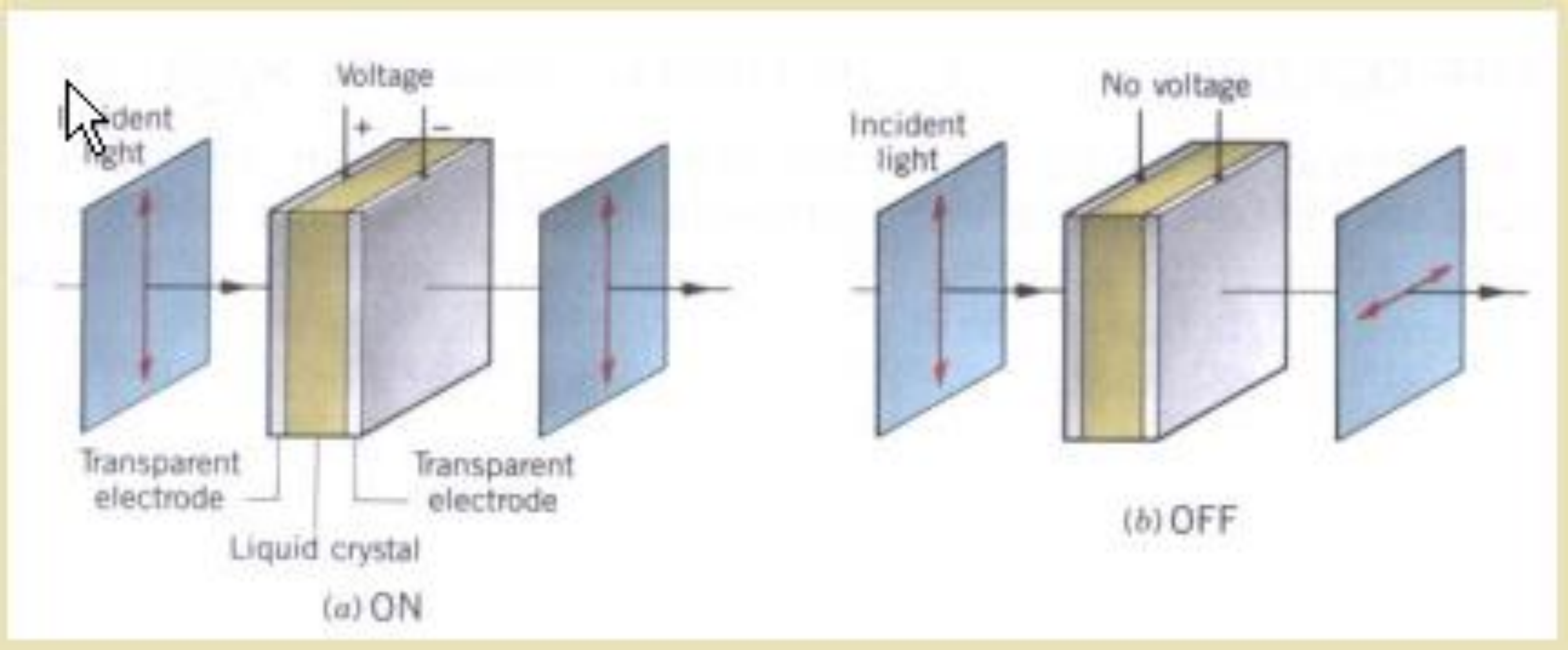
Polarization of Light



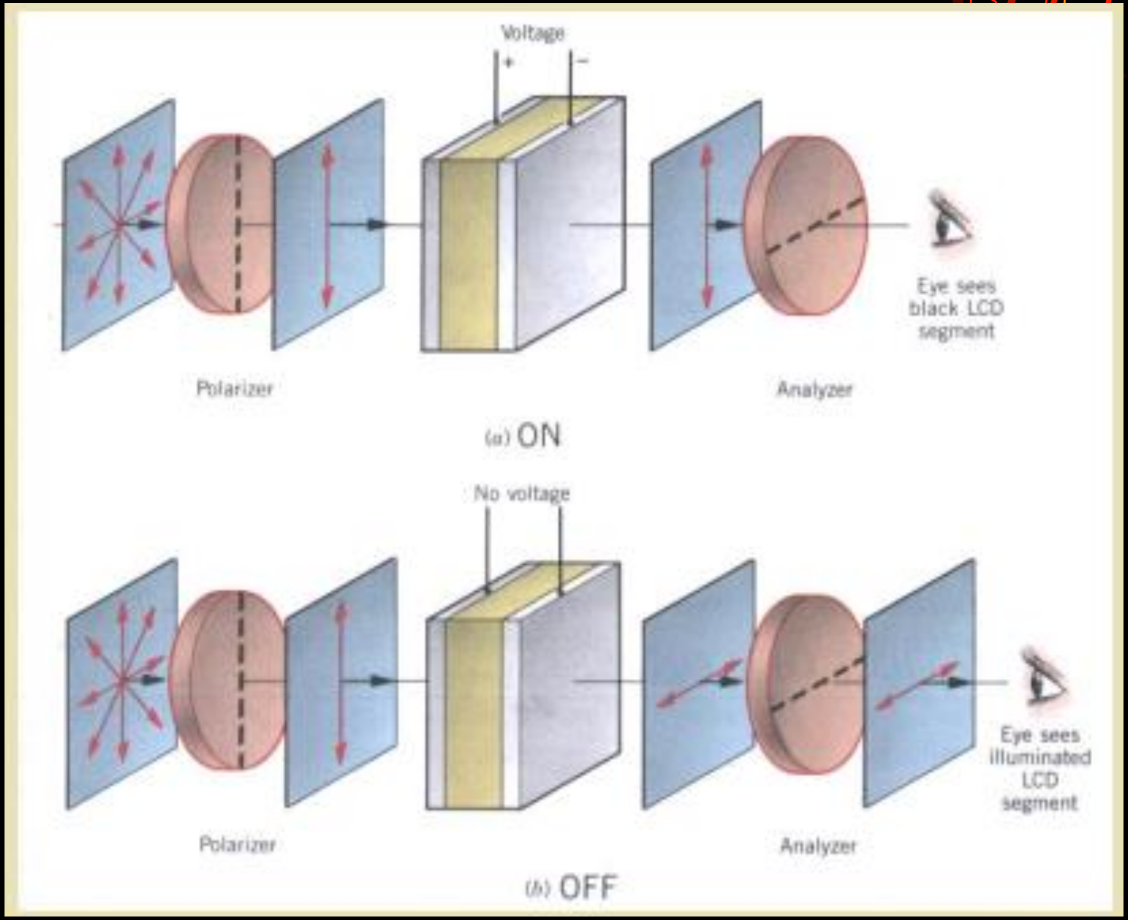
偏振與太陽眼鏡


Transmission axis
Direction of wave travel
Unpolarized light intensity = S
Polarizing material
Polarized light intensity = $\frac{1}{2}S$

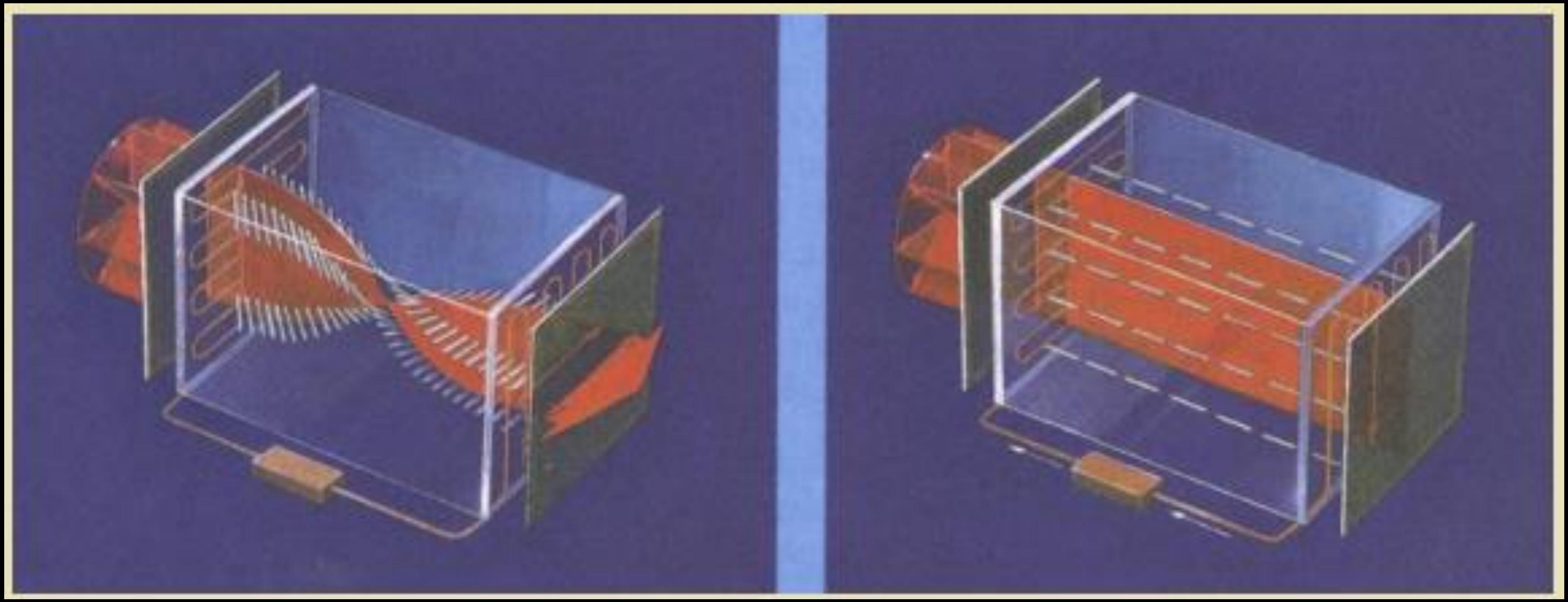
12-4.1 Liquid Crystal - I



Liquid Crystal - II



Liquid Crystal - III



LCD - Liquid Crystal Display