磁 學 (Magnetics)

29~32章探究的主要問題架構

磁場如何形成？其影響為何？

↓

磁力如何產生？其應用為何？

↓

磁場如何估算？

↓

磁如何生電？

↓

磁能如何儲存？

磁 學 (Magnetism)

磁場(The magnetic field)

磁化物質
電流
⇒ Magnetic effect（磁效應）⇒ Compass needle（羅盤針）

●磁場特性
- 磁場線由北極出，南極入，形成封閉環路。
- 地球上無磁單極(monopole)。
- 地理南北極與地磁南北極相反。
- 磁場表示法

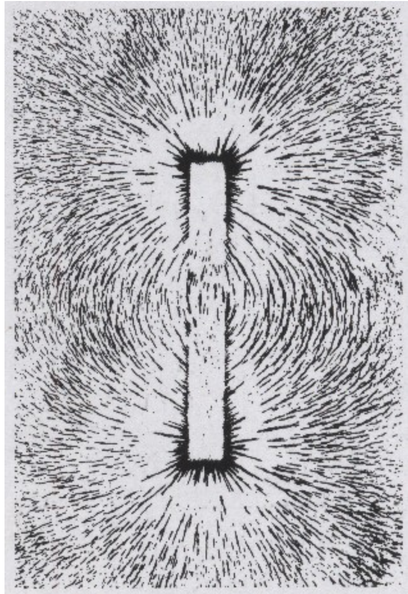


Fig.29.2

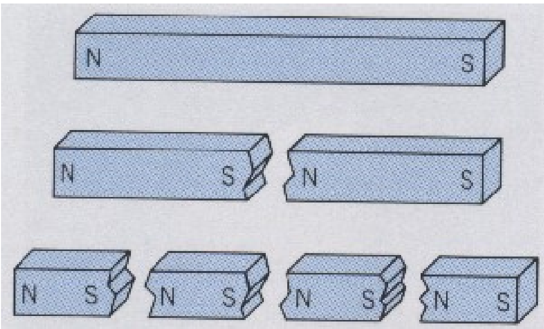


Fig.29.3

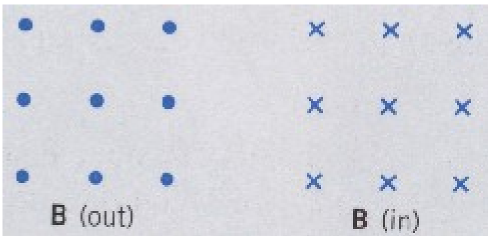
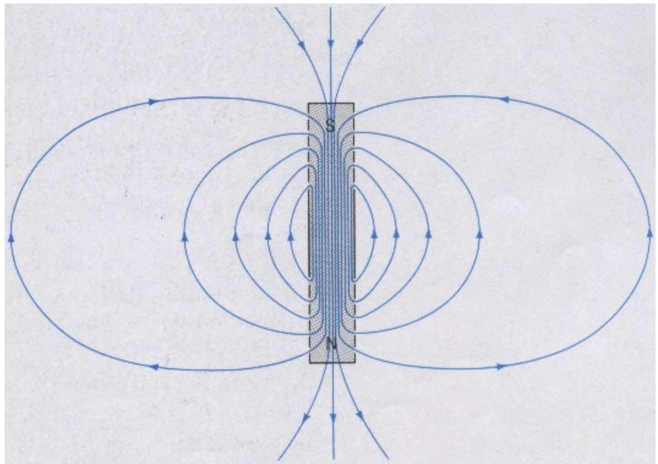


Fig.29.4

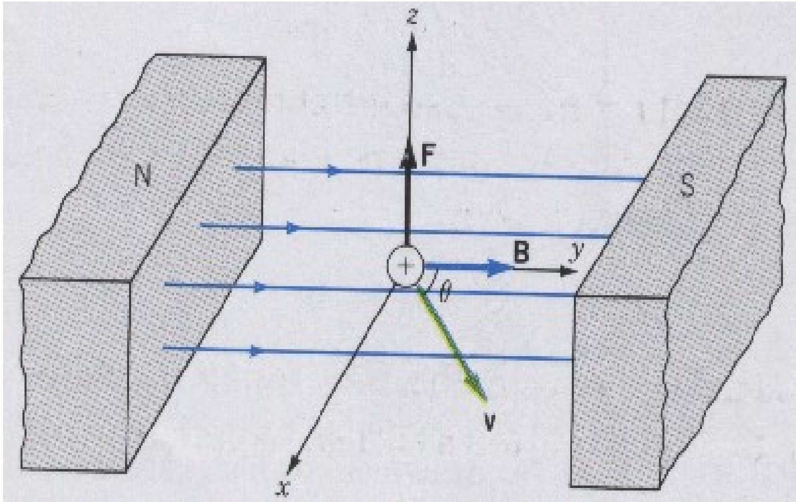


- Definition of the Magnetic Field

－以運動電荷測試磁場 (仿電荷測試電場)

$$\begin{cases} F \propto \sin\theta \\ F \propto qv \end{cases} \Rightarrow F \propto qv\sin\theta$$

Fig.29.5



$\because F \propto B$ $\Rightarrow$定義B為比例常數

$$\Rightarrow F = qvB\sin\theta$$

$$\Rightarrow \vec{F} = q\vec{v} \times \vec{B} \quad \text{(向量式)}$$

$(\because \vec{F} \perp \vec{v} \text{ and } \vec{F} \perp \vec{B})$

(※注意：磁場無法驅動靜止的帶電粒子)

磁力不會作功，不能改變粒子的動能。 $(\because \vec{F} \perp \vec{v})$

SI unit: M.K.S⇒ tesla (T) ； C.G.S⇒Gauss (G)－常用

$1\ \text{T} = 10^4\ \text{G}$

●載流導體上所受的磁力(Force on a current-carrying conductor)

If current-carring wire $\perp \vec{B}$

$$\Rightarrow F = qvB = (nA\ell)ev_d B \quad (\because \begin{cases} q = (nA\ell)e \\ v = v_d \end{cases})$$

$$= I\ell B \quad (\because I = nAev_d)$$

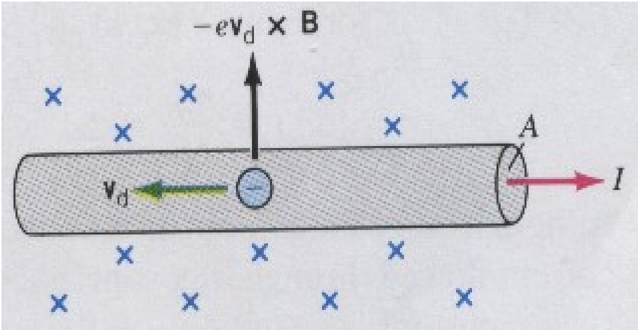


Fig.29.7

If current-carring wire $\not\perp \vec{B} \Rightarrow F = I\ell B\sin\theta \Rightarrow \vec{F} = I\vec{\ell} \times \vec{B}$

If the wire is not straight or the field is not uniform $\Rightarrow d\vec{F} = Id\vec{\ell} \times \vec{B}$

Fig.29.8

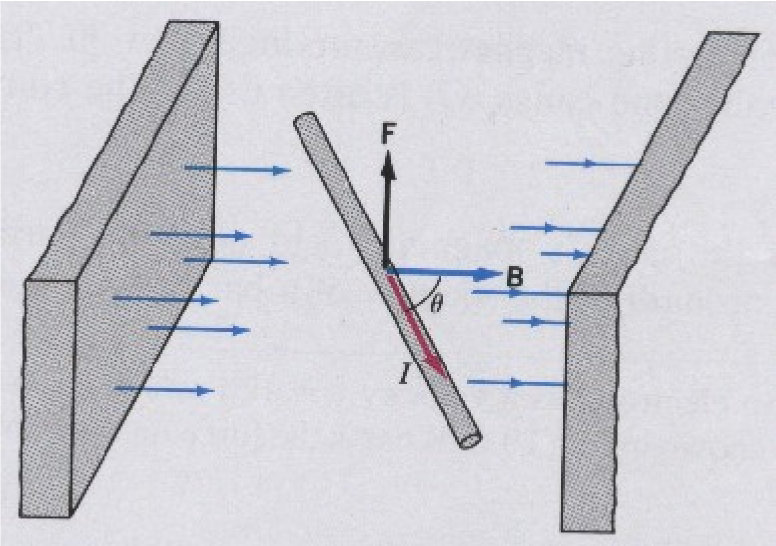
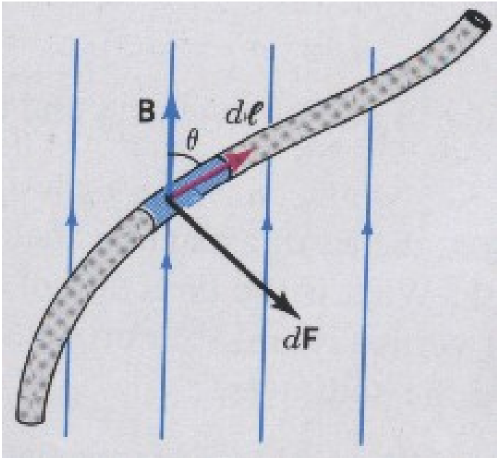


Fig.29.9



Example 29.4: Find the force on the loop for Fig.29.12.

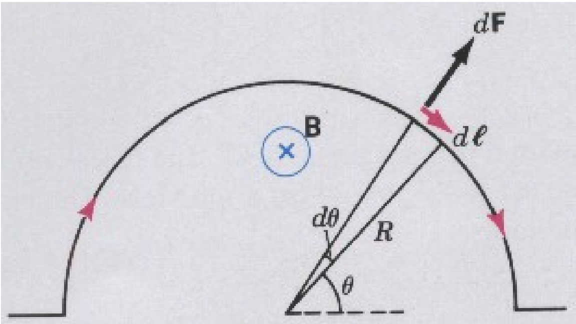


Fig.29.12

電流素(current element)所受磁力 $\begin{cases} \text{x 分量成對抵消} \\ \text{y 分量會疊加} \end{cases}$

➢沿半圓環的總力：

$$dF_y = dF\sin\theta = I(Rd\theta)B\sin\theta$$

$$\Rightarrow F_y = IRB\int_0^{\pi}\sin\theta d\theta = IRB\left[-\cos\theta\right]_0^{\pi} = 2IRB$$

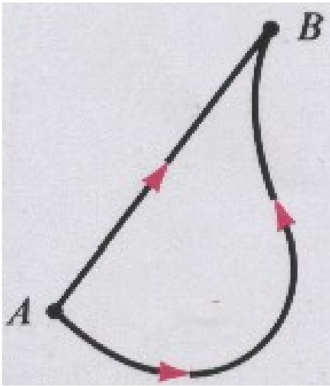


Fig.29.13

➢直線連接半圓環(或Fig.29.13之AB)兩端的總力：

$$F_y = \int_0^{2R} IBd\ell = IB\int_0^{2R} d\ell = 2IRB$$

➢延伸應用：

1.A→B任一路徑所受磁力皆為$2IRB$，B→A則為$-2IRB$。

2.在一均勻磁場內，任一封閉載流線圈的淨力為零。

單匝載流線圈所受的力矩(Torque on a current loop)

●均勻磁場 $\begin{cases} \text{淨力(net force)或合力為零。} \\ \text{淨轉矩(net torqe)或合力矩不一定為零。} \end{cases}$

考慮Fig.29.14的矩形迴路
(邊長a與c)

$$\xrightarrow[\text{僅考慮}c\text{邊作用力}]{z\text{軸為轉軸}} \begin{cases} \vec{F}_1 = I(-c\hat{k})\times(B\hat{i}) = -IcB\hat{j} \\ \vec{F}_2 = I(c\hat{k})\times(B\hat{i}) = IcB\hat{j} \end{cases}$$

$$\tau_{net} = r_\perp F_1 + r_\perp F_2 = 2(IcB)\left(\frac{a}{2}\sin\theta\right) = IAB\sin\theta$$

$(\because r_\perp = \frac{a}{2}\sin\theta)$ (where A=ac)

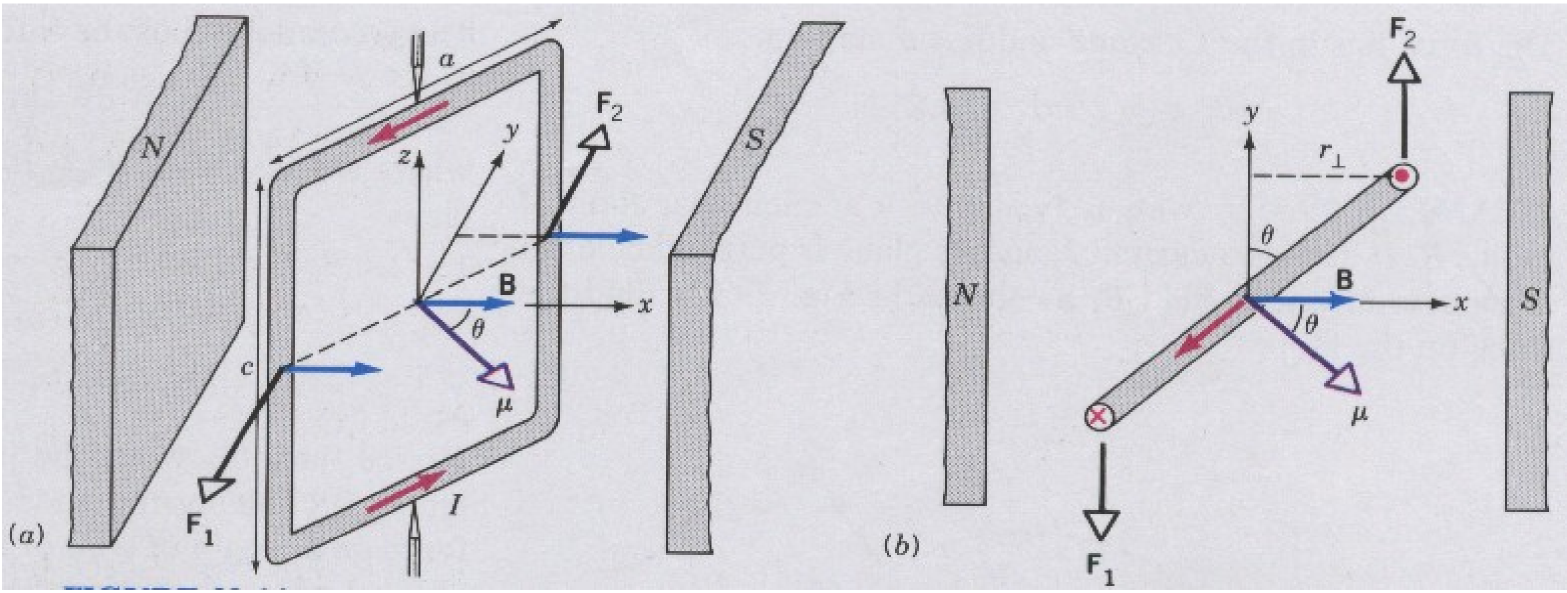


Fig.29.14

Magnetic dipole moment (磁偶極矩) $\xrightarrow{is\ defined\ as} \vec{\mu} = NIA\hat{n}$

<其中 $\hat{n}$ 為線圈平面法線方向(可依右手定則判定)，N表匝數，SI unit: $A \cdot m^2$ >

N匝線圈 $\Rightarrow \tau = NIAB\sin\theta \Rightarrow \vec{\tau} = \vec{\mu} \times \vec{B}$

（此力矩使磁偶極矩沿磁場方向排列）

$$\Delta U = \int \tau d\theta = \int_{\theta_1}^{\theta_2} \mu B \sin\theta d\theta$$

$$\Rightarrow U_2 - U_1 = \mu B \cos\theta_1 - \mu B \cos\theta_2$$

令 $U_1 = 0, \quad \theta_1 = \pi/2 \ \Rightarrow \ U = -\vec{\mu} \cdot \vec{B}$

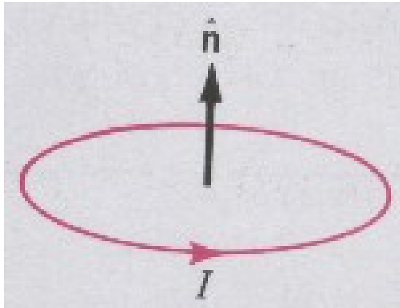


Fig.29.15

近似電偶極矩在均勻電場的形式 $\Rightarrow \begin{cases} \vec{\tau} = \vec{p} \times \vec{E} \\ U = -\vec{p} \cdot \vec{E} \end{cases}$

●應用：

➢檢流計(Galvanometer)

Moving-coil galvanometer
（圈動檢流計）

⇩

$\tau_B = \mu B \sin\theta$ (from magnetic field)

$\tau_{sp} = \kappa\phi$ (from a coiled spring)

$NIAB \sin\theta = \kappa\phi$

⇩

為了刻度線性化(消去sinθ)，將磁極改為圓柱形，則θ=π/2。

$$NIAB = \kappa\phi \Rightarrow \phi = \frac{NAB}{\kappa} I$$

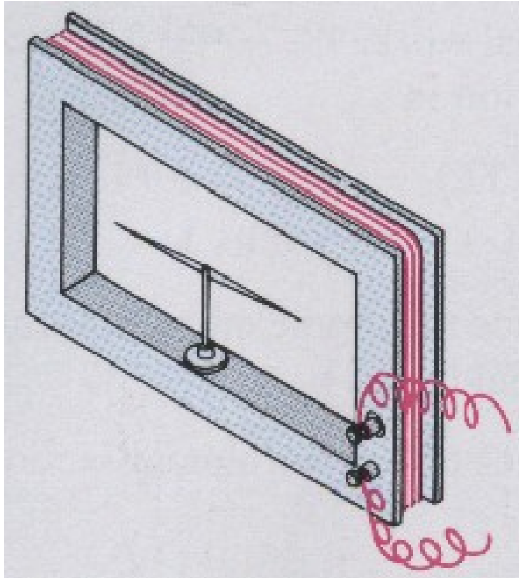


Fig.29.17

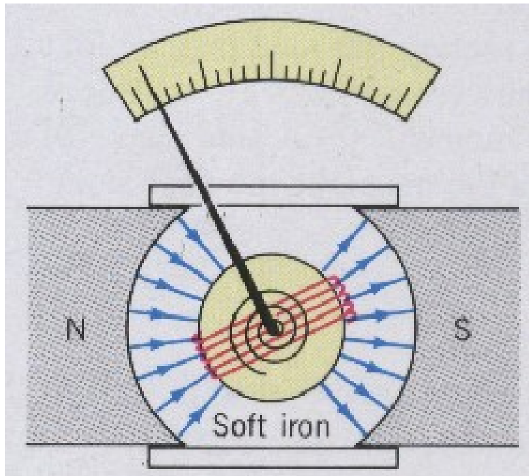


Fig.29.18

➢DC motor（直流電動機）— 利用磁場中載流線圈的轉矩作功，並藉由換向器(commutator)讓線圈朝某一方向持續旋轉，其中還需利用慣性克服換向器的空隙無電流區。

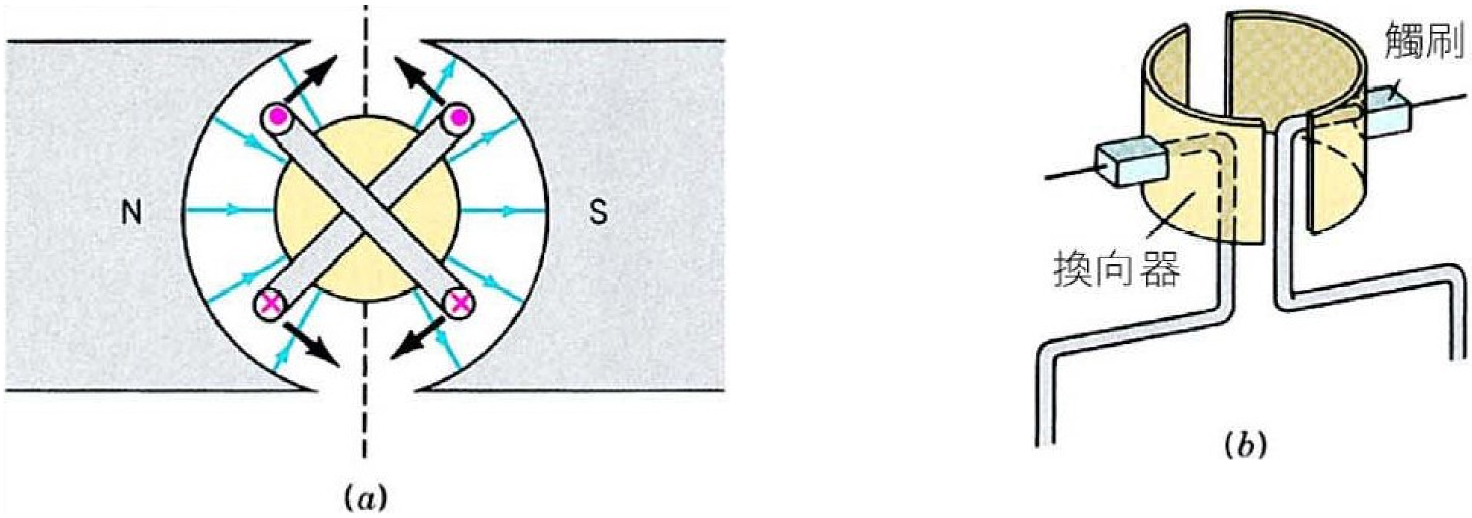


Fig.29.20

帶電粒子在磁場中的運動 $\xrightarrow{\text{一般的應用}}$ $\begin{cases} TV\ \ tube(\text{電視印象管的聚焦}) \\ fusion\ control(\text{核熔合控制}) \\ \text{地磁對高能粒子的束縛} \end{cases}$

(the motion of charged particles in magnetic fields)

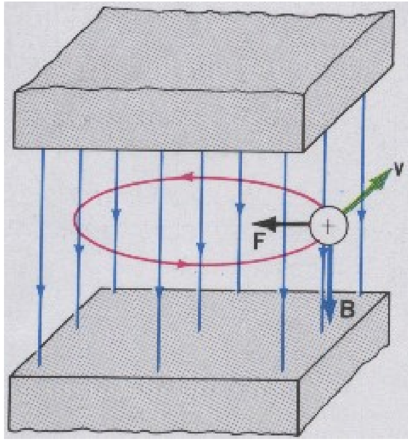
●均勻磁場：

➢Case(A): 若 $\vec{v} \perp \vec{B}$ (即垂直入射)，則粒子為圓周運動。

$$\Rightarrow F_B(\text{磁力}) = qvB = \frac{mv^2}{r}(\text{向心力}) \ \Rightarrow r = \frac{mv}{qB}$$

$$\Rightarrow T = \frac{2\pi r}{v} = \frac{2\pi m}{qB} \ \Rightarrow f_c = \frac{1}{T} = \frac{qB}{2\pi m}$$

$\begin{cases} r\ \text{稱為迴旋半徑(cyclotron radius or gyroradius)} \\ f_c\ \text{稱為迴旋頻率(cyclotron frequency)} \end{cases}$



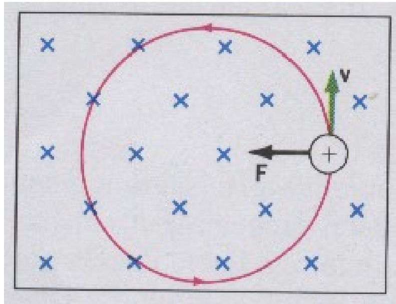


Fig.29.22

Conclusion：

(i)週期與頻率皆與粒子速率無關。

(ii)荷值比(q/m)相同的粒子亦具有相同的迴旋週期與頻率。

➢Case(B): 若 $\bar{v} \not\perp \bar{B}$ (即傾斜入射，$\bar{v}$與$\bar{B}$夾有角度θ) ，則粒子為螺旋運動。
(Helical motion)

$$\Rightarrow \begin{cases} \bar{v}_{\parallel}\text{表平行}\bar{B}\text{的分量} \xrightarrow{\text{不受磁場B影響}} \text{直線運動} \\ \bar{v}_{\perp}\text{表垂直}\bar{B}\text{的分量} \xrightarrow{\text{磁力為向心力}} \text{圓周運動} \end{cases}$$

螺旋線的一螺距(pitch)即一週期的粒子位移大小。

$$\Rightarrow d = v_{\parallel}T = v_{\parallel}\frac{2\pi m}{qB}$$

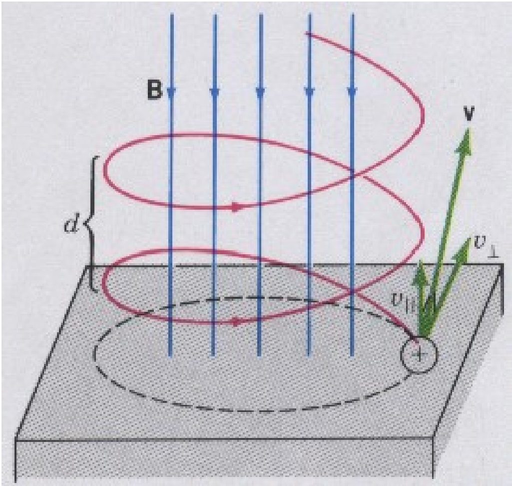


Fig.29.23

●非均勻磁場

⇒ {
迴旋半徑與磁場強度成反比，即 $r \propto 1/B$。
粒子所受磁力朝著磁場較弱區域。

Magnetic bottles(磁瓶) effect

— 當粒子朝向磁場強度較強的區域運動，則會在某一點停止前進並開始倒逆其行進方向。

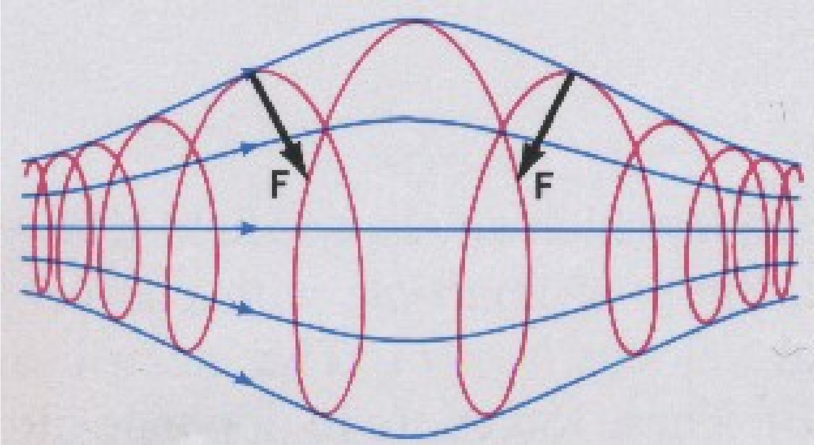


Fig.29.24

應用 {
控制高溫電漿(plasma)，如：核熔合反應研究。
將高能粒子控制在地磁區域而形成凡阿侖輻射帶。(Van Allen radiation belts)

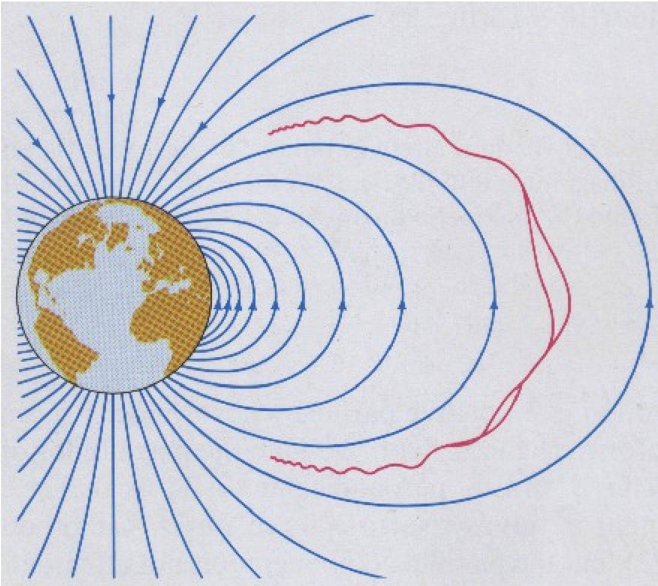


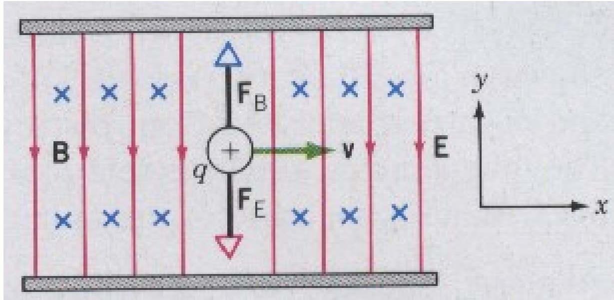
Fig.29.25

帶電粒子受電場與磁場的交叉場(crossed fields)聯合作用

$$\Rightarrow \vec{F} = \vec{F}_E + \vec{F}_B = q(\vec{E} + \vec{v} \times \vec{B})$$ — Lorentz force (勞侖茲力)

$Case: \vec{E} = -E\hat{j},\ \vec{B} = -B\hat{k}$ (shown as Fig.29.26)

Fig.29.26



$$\Rightarrow \begin{cases} \vec{F}_E = -qE\hat{j} \\ \vec{F}_B = qvB\hat{j} \end{cases} \Rightarrow \ If\ \vec{F}_E + \vec{F}_B = -qE\hat{j} + qvB\hat{j} = 0$$

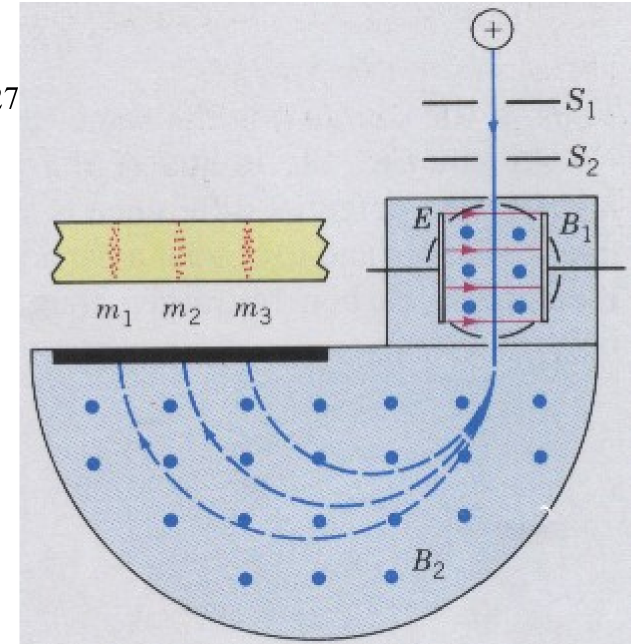
(帶電粒子進入crossed fields未偏向)

$$\Rightarrow \vec{E} + \vec{v} \times \vec{B} = 0 \ \Rightarrow \vec{E} = -\vec{v} \times \vec{B} \xrightarrow{if\ \vec{v} \perp \vec{B}} v = \frac{E}{B}$$

• 應用 ⇒ Mass spectrometer(質譜儀)

— 可分離同位素，偵測污染物或雜質

Fig.29.27



$$r = \frac{mv}{qB} \Rightarrow \frac{m}{q} = \frac{Br}{v}$$

$$\xrightarrow{v = E/B_1} \frac{m}{q} = \frac{B_1 B_2}{E} r$$

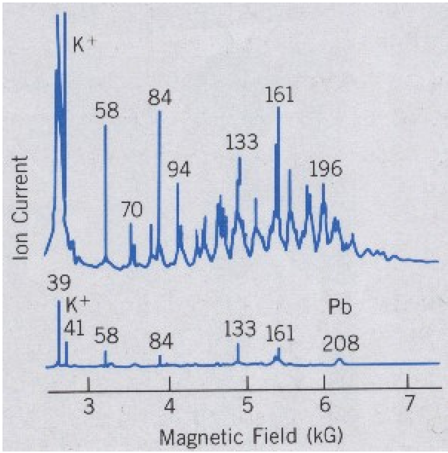


Fig.29.28

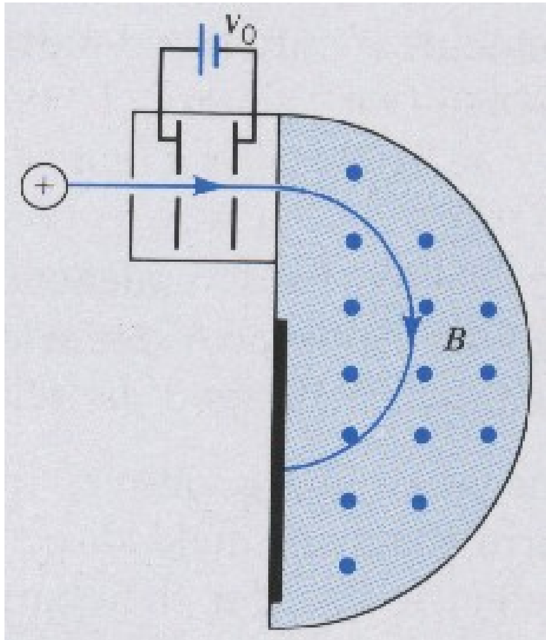
Example 29.9: (A.J. Dempster's mass spectrometer)

Two isotopes of an element with m_1 and m_2 are accelerated from rest by a potential difference V. They then enter a uniform field B normal to the magnetic field lines. What is the ratio of the radii of their paths?

$$\text{Kinetic energy} \Rightarrow \frac{1}{2}mv^2 = qV \Rightarrow v = \sqrt{\frac{2qV}{m}}$$

$$\text{the radius of the path} \Rightarrow r = \frac{mv}{qB} = \sqrt{\frac{2mV}{qB^2}}$$

$$\Rightarrow \frac{r_1}{r_2} = \sqrt{\frac{m_1}{m_2}}$$



The Hall effect (霍[哈]耳效應)

磁力作用於載流導線
(因不論磁場是否存在，導體內電流分佈皆相同)－Maxwell

⇒

磁力與電流成正比，跟導線size無關。(因電流為零，磁力便消失)－Hall

⇒

在磁場中，fluid被磁力拉向導線一邊，促使有效截面減小，電阻將增大。

⇒

在磁場中，電荷$+q$以v_d沿金屬片移動時，會受到向上的磁力，造成金屬片頂部帶正電，底部帶負電，形成向下的Hall電場，導致一個向下的靜電力。當更多電荷移往金屬頂部與底部，靜電力會增大，最後與磁力平衡後，電荷便不再偏向。

$$\begin{cases} \vec{F}_B = qv_d B\hat{k} \\ \vec{F}_E = -qE\hat{k} \end{cases} \Rightarrow F_B = F_E \quad \Rightarrow E = v_d B$$

$$\text{霍耳電壓} \Rightarrow V_H = EW = v_d BW$$

(Hall potential difference)

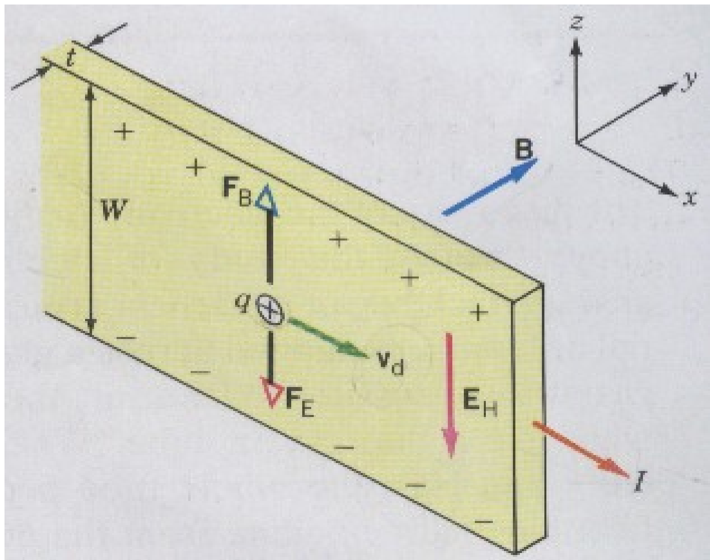


Fig.29.34

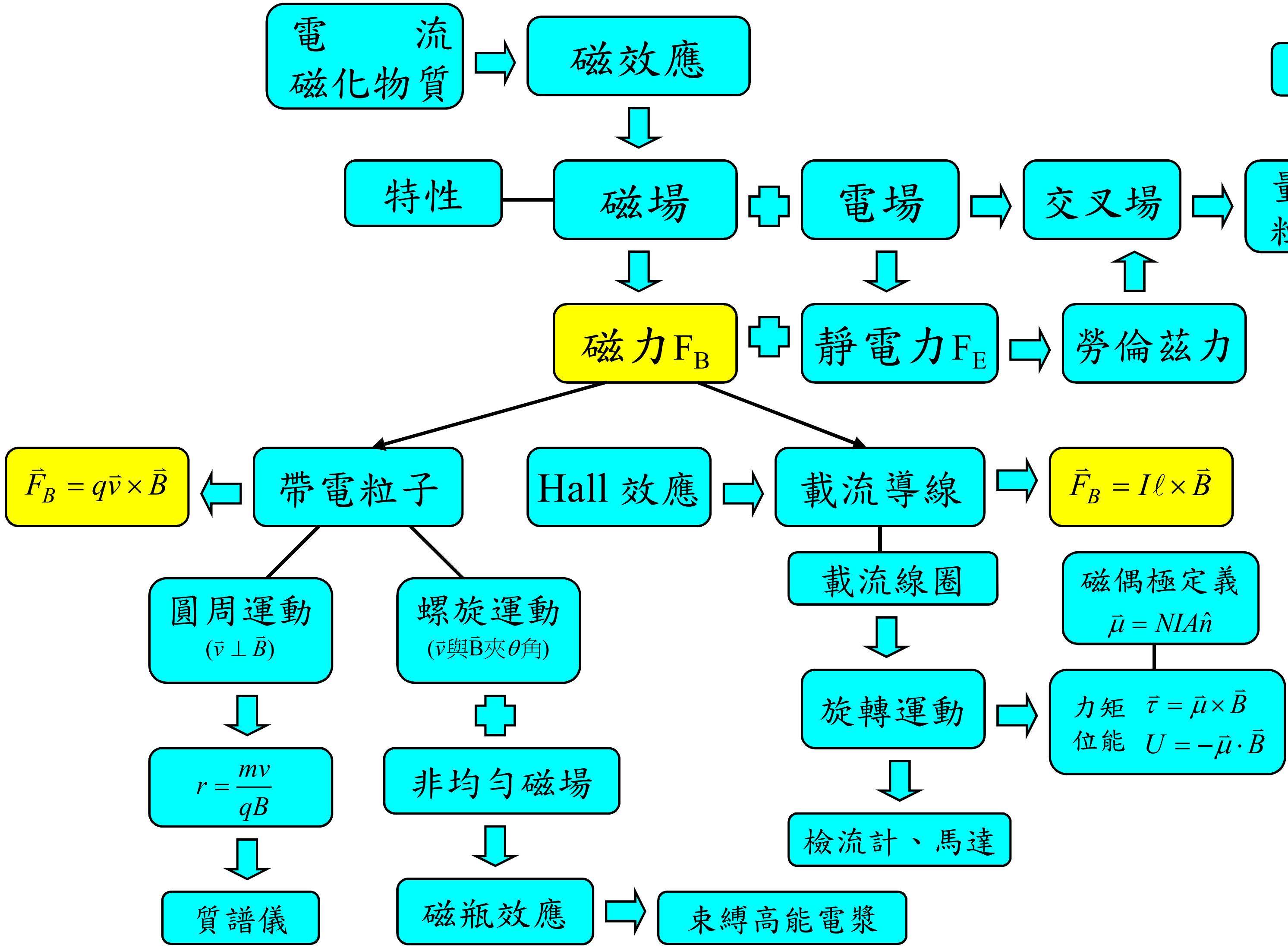
$$\because \begin{cases} I = nqv_d A \\ A = Wt \end{cases} \Rightarrow v_d = \frac{I}{nqWt} \quad , \therefore\ V_H = v_d BW = \frac{IB}{nqt}$$

應用 ⇒
- 霍耳電壓(V_H)極性可判知導體內移動電荷為負。
- 磁場已知，可求漂移速度v_d；或v_d已知，可求磁場B。
- 霍耳探針(Hall probe)－利用哈耳電壓量測磁場。
- 霍耳電壓(V_H)反比於載流電荷密度(n)。

補充 ⇒
- Au, Cu, Ag, Pt, Al 的V_H 極性偏向負電荷載體。
- Co, Zn, Pb, Fe 及半導體Si, Ge的V_H 極性偏向正電荷載體。

作用於載流導線上的磁力性質(The nature of the magnetic force on a current-carrying wire)－磁力並非直接作用於導線上，因導線晶格上的正離子幾乎靜止不動(除熱運動之外)，不會產生磁力，但導線內漂移的負電荷卻可由 Hall effect 在導線兩側形成電場，促使導線正離子產生靜電力(F=qE，靜止於電場中的電荷仍具靜電力)，此力相當於磁力，作用於導線晶格的正離子上。

本章單元重要觀念發展脈絡彙整



習 題

- 教科書習題 (p.599~p.604)

  Exercise: 7,11,21,25,31,35,39,59,75,77

  Problem: 5

- 基本觀念問題：

  1.請說明磁偶極矩(magnetic dipole moment)μ的定義(包括：大小與方向)，並寫出均勻磁場B對磁偶極矩μ所造成的力矩及位能向量式。

  2.請說明磁瓶效應。

  3.請利用霍爾效應(Hall effect)解釋載流導線受磁力的作用。

磁場的來源(Source of magnetic field)－由運動的電荷(電流)產生

- 無窮長直載流導線形成的磁場 (Infinite wire) $B \Rightarrow \begin{cases} B \propto 1/R \\ B \propto I \end{cases} \xrightarrow{\text{SI unit}} B = \dfrac{\mu_0 I}{2\pi R}$

其中 $\mu_0 = 4\pi \times 10^{-7}\, T \cdot m / A \rightarrow$ permeability constant (導磁常數)

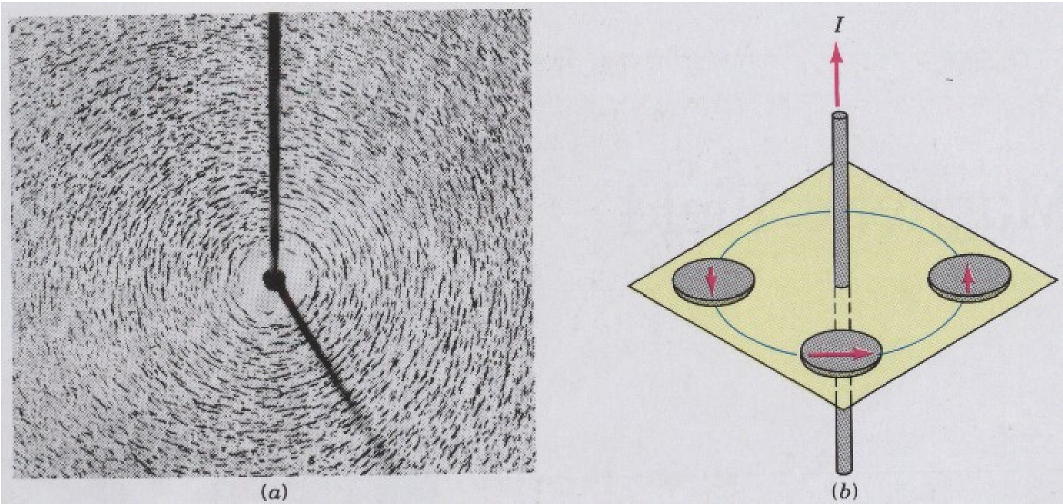


Fig.30.1

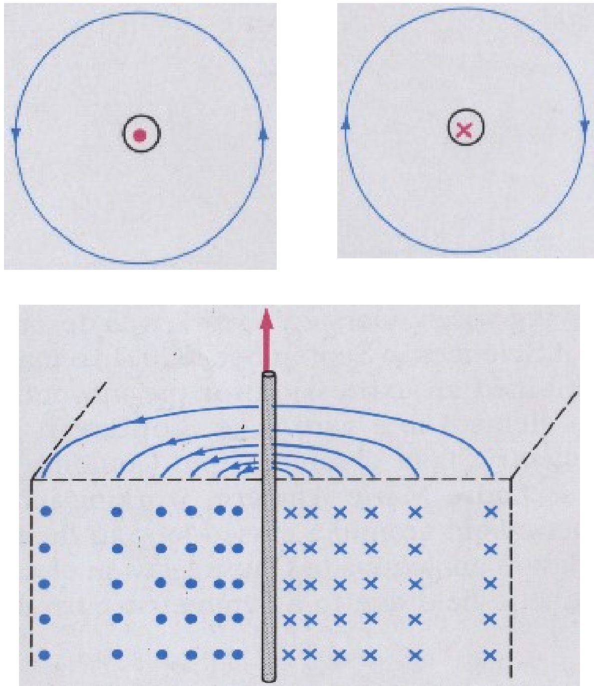


Fig.30.2

- 平行導線間的磁力(Magnetic force between parallel wires)

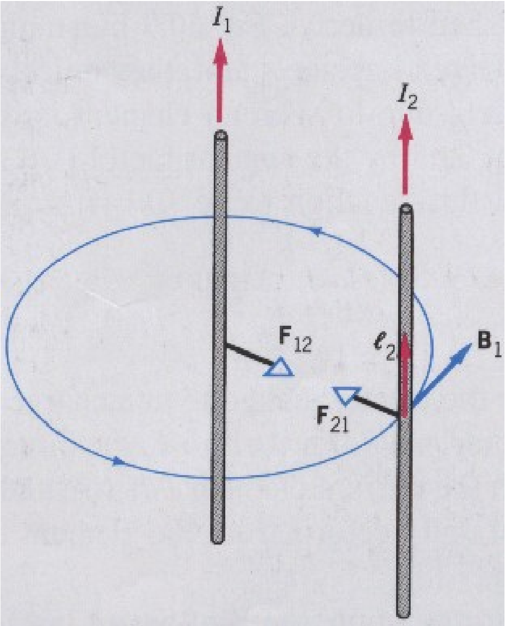


Fig.30.3

若考慮wire 1形成的磁場B_1，則wire 2部份長度ℓ_2 所受磁力為 $\vec{F}_{21}$

或考慮wire 2形成的磁場B2，則wire 1部份長度ℓ_1 所受磁力為 $\vec{F}_{12}$

$$\Rightarrow \vec{F}_{21} = I_2\vec{\ell}_2\times\vec{B}_1 \quad \text{或} \quad \vec{F}_{12} = I_1\vec{\ell}_1\times\vec{B}_2$$

➢考慮 $\ell_1=\ell_2$

$$\Rightarrow F_{21} = I_2\ell_2 B_1 = I_2\ell_2\frac{\mu_0 I_1}{2\pi d} = \frac{\mu_0 I_1 I_2\ell_2}{2\pi d} = F_{12}$$

➢考慮 $\ell_1=\ell_2=\ell$

單位長度所受磁力 $\Rightarrow \dfrac{F}{\ell} = \dfrac{\mu_0 I_1 I_2}{2\pi d}$

$\boxed{\text{結論}}$ $\Rightarrow$

- 安培定義的基礎 $\Rightarrow \ell = 1\text{m},\ d = 1\text{m},\ I_1 = I_2 = 1A \ \Rightarrow F = 2\times10^{-7}\,N$
- 若I_1與I_2同向，則兩導線相吸；若I_1與I_2反向，則兩導線相斥。

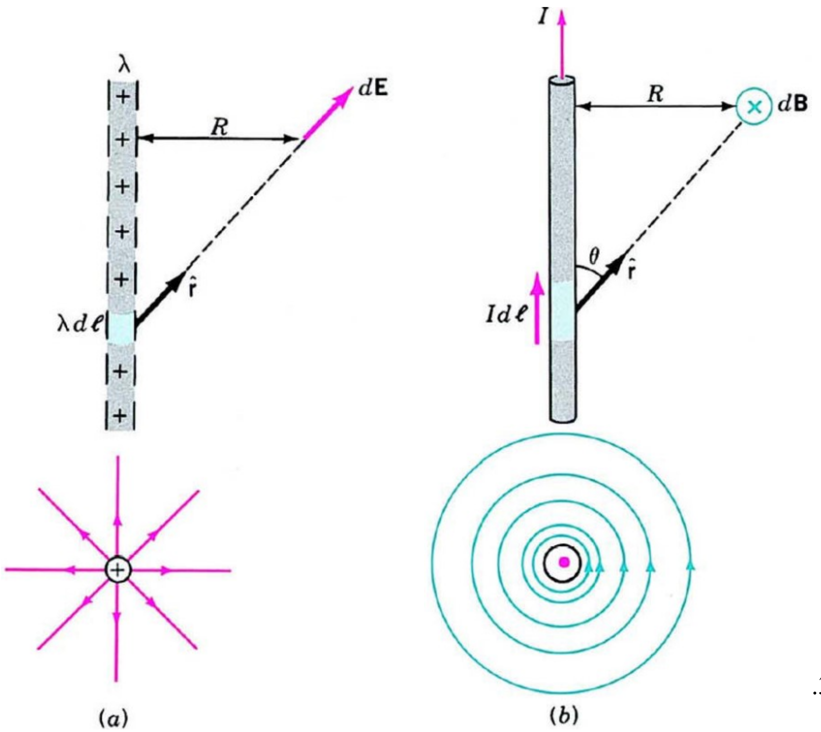
$\text{磁場計算} \Rightarrow \begin{cases} \text{Biot-Savart Law (Current element) to Coulomb Law (point charge)} \\ \text{Ampere's Law (closed loop) to Gauss's Law (closed surface)} \end{cases}$

•Biot-Savart Law (必歐沙伐定律)－類似庫侖定律

$$\text{無窮長直導線} \Rightarrow E = \frac{2k\lambda}{R} \xrightarrow{\text{對照}} B = \frac{2k'I}{R} \quad (k' = \mu_0 / 4\pi)$$

$$\text{推導應用方法} \Rightarrow d\vec{E} = k\frac{\lambda d\ell}{r^2}\hat{r} \xrightarrow{\text{對照}} d\vec{B} = k'\frac{Id\vec{\ell} \times \hat{r}}{r^2}$$

$$(\because dq = \lambda d\ell)$$



$$\Rightarrow d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{\ell} \times \hat{r}}{r^2}$$

（向量表示式）

$$\Rightarrow dB = \frac{\mu_0}{4\pi}\frac{Id\ell \sin\theta}{r^2}$$

（純量式－求磁場大小）

Example 30.2 An infinite straight wire carries a current I

$$\left|d\vec{\ell}\times\hat{r}\right| = d\ell\sin\theta \;\; = d\ell\sin(\pi-\theta) = d\ell\cos\alpha$$

$$\because \ell = R\tan\alpha \Rightarrow d\ell = R\sec^2\alpha d\alpha \;;\; r = R\sec\alpha$$

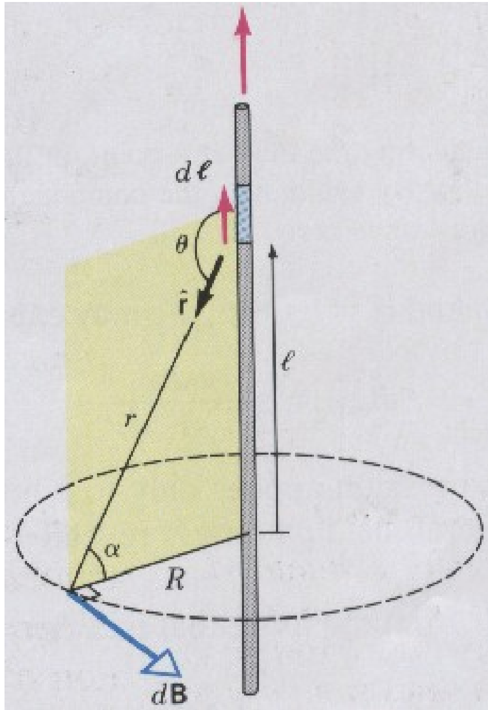


Fig.30.6

$$\therefore B = \int dB = \frac{\mu_0 I}{4\pi}\int_{-\alpha_1}^{\alpha_2}\frac{\left|d\vec{\ell}\times\hat{r}\right|}{r^2} = \frac{\mu_0 I}{4\pi}\int_{-\alpha_1}^{\alpha_2}\frac{d\ell\cos\alpha}{R^2\sec^2\alpha}$$

$$= \frac{\mu_0 I}{4\pi}\int_{-\alpha_1}^{\alpha_2}\frac{(R\sec^2\alpha d\alpha)\cos\alpha}{R^2\sec^2\alpha}$$

$$= \frac{\mu_0 I}{4\pi R}\int_{-\alpha_1}^{\alpha_2}\cos\alpha d\alpha \;\; = \frac{\mu_0 I}{4\pi R}(\sin\alpha_1 + \sin\alpha_2)$$

For an infinite wire $\Rightarrow B = \dfrac{\mu_0 I}{4\pi R}\displaystyle\int_{-\pi/2}^{\pi/2}\cos\alpha d\alpha$

$$= \frac{\mu_0 I}{4\pi R}[\sin(\pi/2) + \sin(\pi/2)] \;\; = \frac{\mu_0 I}{2\pi R}$$

Example 30.3 A circular loop of radius a carries a current I

$$\begin{cases} dB_{\perp}\text{分量會成對抵消} \\ dB_{axis}\text{分量可重疊累加} \end{cases}$$

$$\Rightarrow dB_{axis} = dB\sin\alpha = \left(\frac{\mu_0 I d\ell}{4\pi r^2}\right)\left(\frac{a}{r}\right)$$

$$\left(\because d\vec{\ell} \perp \hat{r},\ \therefore dB = \frac{\mu_0 I}{4\pi}\frac{\left|d\vec{\ell}\times\hat{r}\right|}{r^2} = \frac{\mu_0 I d\ell}{4\pi r^2}\right)$$

$$B_{axis} = \int dB_{axis} = \frac{\mu_0 I a}{4\pi r^3}\int_0^{2\pi a} d\ell = \frac{\mu_0 I a}{4\pi r^3}(2\pi a)$$

$$= \frac{\mu_0 I a^2}{2r^3} = \frac{\mu_0 I a^2}{2\left(a^2+z^2\right)^{3/2}}$$

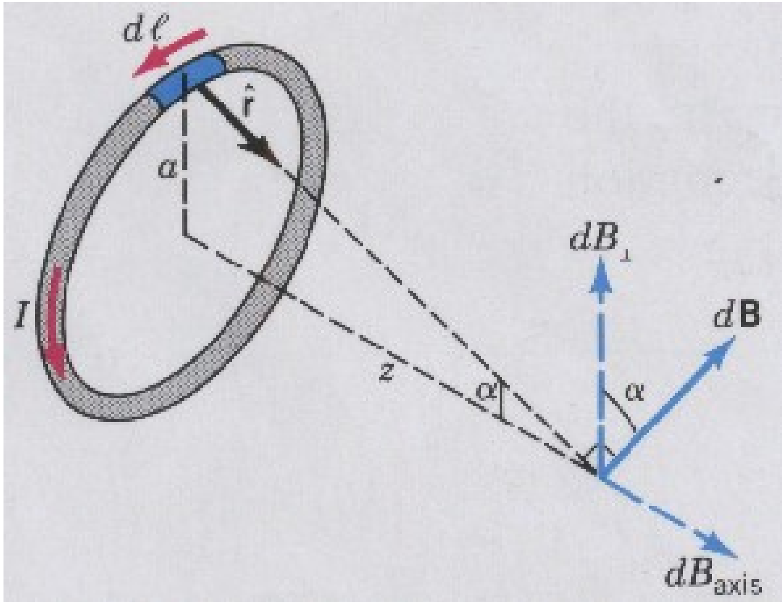


Fig.30.7

For far field, that is, $z >> a \Rightarrow B_{axis} = \dfrac{\mu_0 I a^2}{2\left(a^2+z^2\right)^{3/2}} \approx \dfrac{\mu_0 I a^2}{2z^3} = \dfrac{\mu_0 I \pi a^2}{2\pi z^3} = \dfrac{2k'\mu}{z^3}$

(where $k' = \dfrac{\mu_0}{4\pi}$, $\mu = IA = I\pi a^2$)

(相當於dipole moment的磁場)

$$E = \frac{2kp}{z^3}$$ (沿電偶極極軸的遠處電場)－如圖(a)

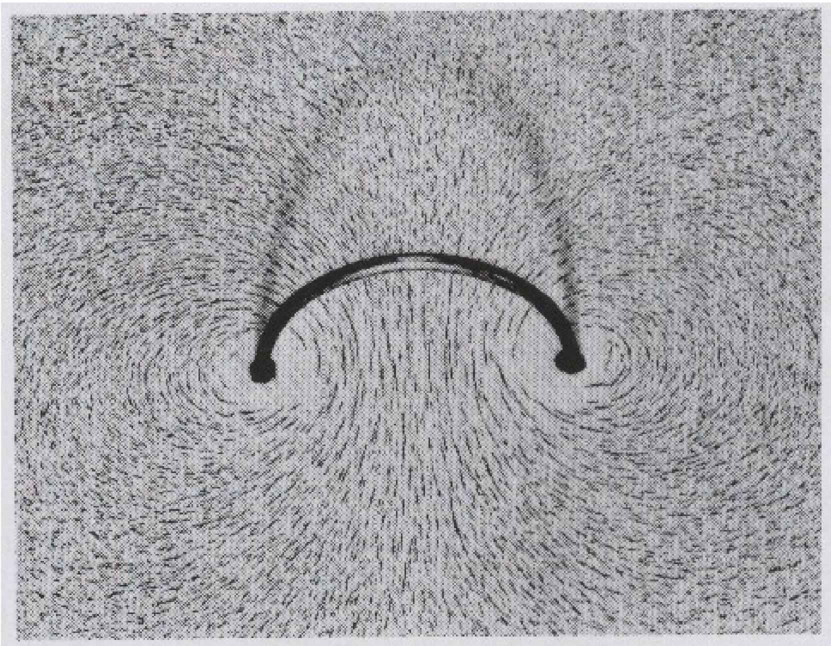


Fig.30.8

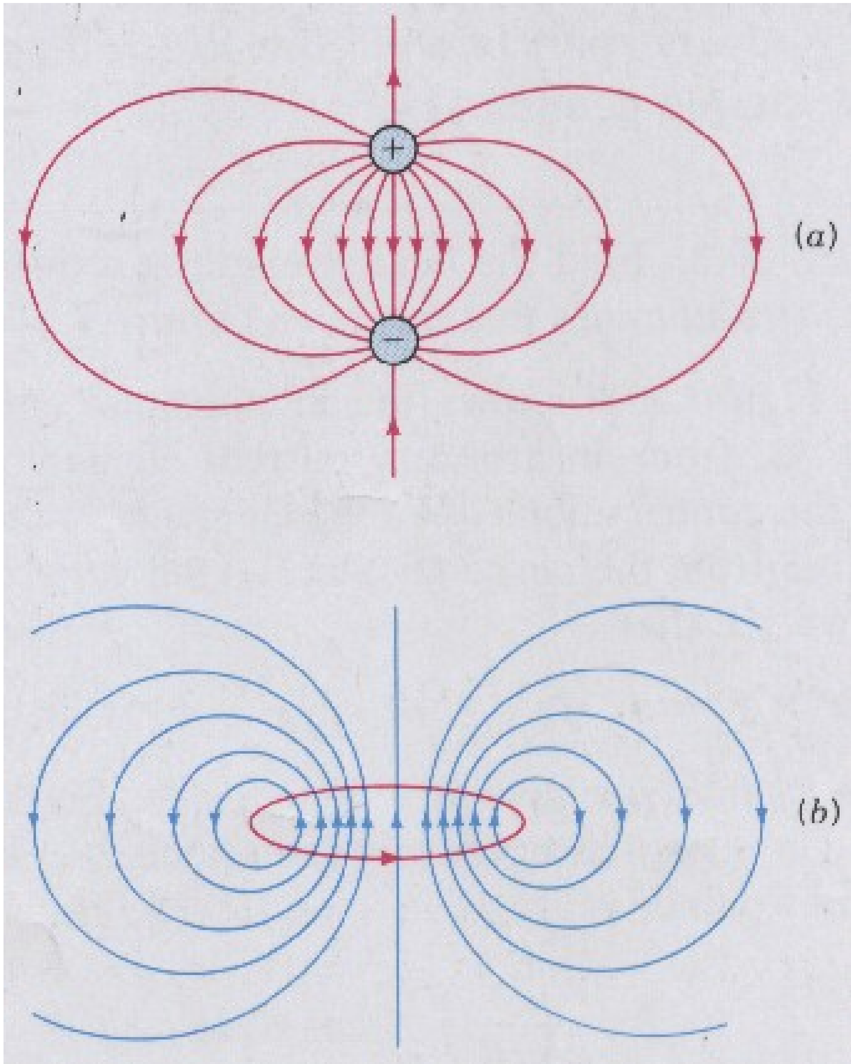


Fig.30.9

$$B = \frac{2k'\mu}{z^3}$$ (沿環形線圈中央軸的遠處磁場)－如圖(b)

單一環形線圈
(遠場近似dipole)

⇨

多匝環形線圈
(線圈內部磁場最強且近似均勻，線圈外部磁場最弱)

⇨

螺旋線管(solenoid)
(線圈匝數更多更密)
—管內磁場均勻且最大，管外近似為零

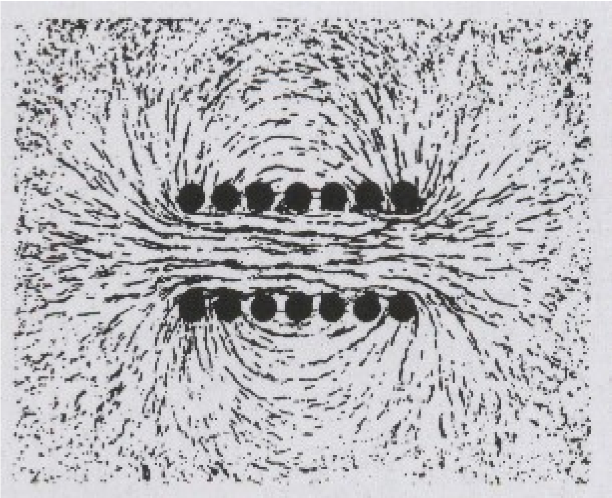


Fig.30.10

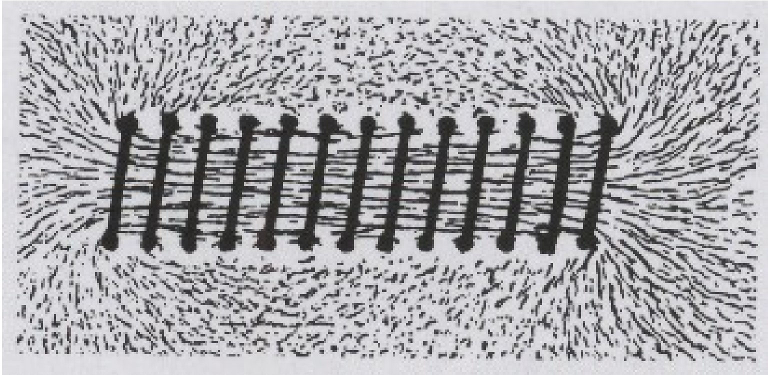
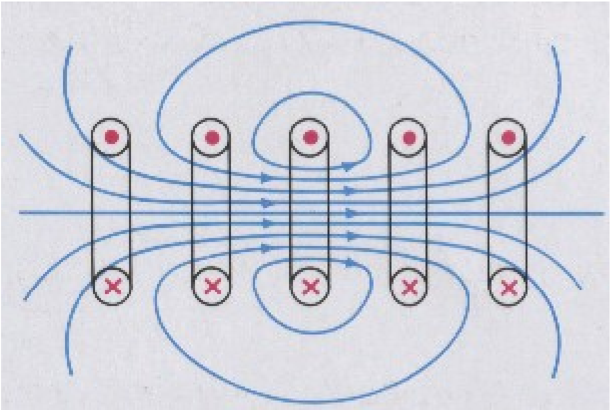
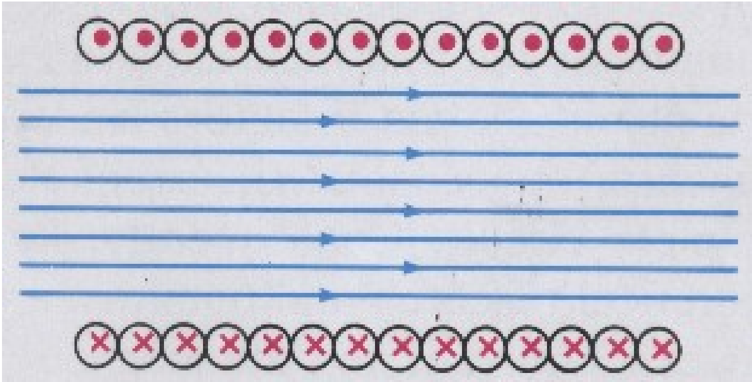


Fig.30.12





Example 30.4 A solenoid of length *l and radius a* has N turns of wire and carries a current *I*

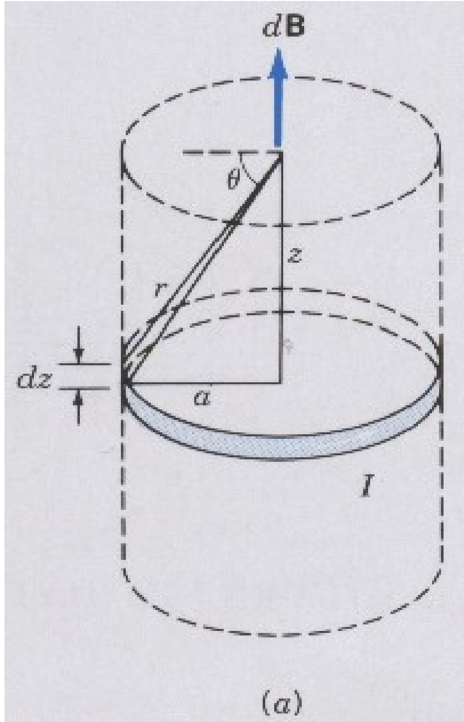


Fig.30.13

$$z = a\tan\theta \Rightarrow dz = a\sec^2\theta d\theta$$

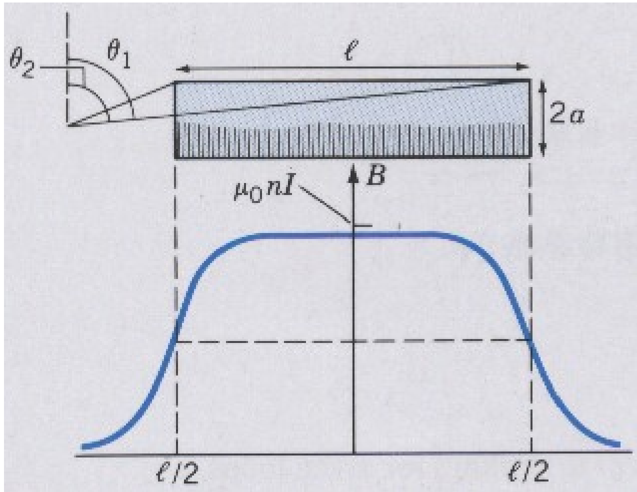
The current of a loop $\xrightarrow{n=N/\ell} nIdz = nIa\sec^2\theta d\theta$

From circular loop: $B_{axis} = \dfrac{\mu_0 I a^2}{2\left(a^2+z^2\right)^{3/2}}$

$$\Rightarrow dB = \frac{\mu_0(nIdz)a^2}{2\left(a^2+z^2\right)^{3/2}} = \frac{\mu_0 nIa^3\sec^2\theta d\theta}{2\left(a^2+a^2\tan^2\theta\right)^{3/2}}$$

$$= \frac{\mu_0 nIa^3\sec^2\theta d\theta}{2a^3\sec^3\theta} = \frac{1}{2}\mu_0 nI\cos\theta d\theta$$

$$B = \frac{1}{2}\mu_0 nI\int_{\theta_1}^{\theta_2}\cos\theta d\theta = \frac{1}{2}\mu_0 nI(\sin\theta_2 - \sin\theta_1)$$



For a infinite solenoid $\xrightarrow{\theta_1=-\pi/2,\ \theta_2=\pi/2} B = \mu_0 nI$

•Ampere's Law (安培定律)－類似高斯定律

主要應用於無窮長直導線 $\Rightarrow B=\dfrac{\mu_0 I}{2\pi R}\Rightarrow B(2\pi r)=\mu_0 I$（考慮圓形路徑）

(磁力線為同心圓)

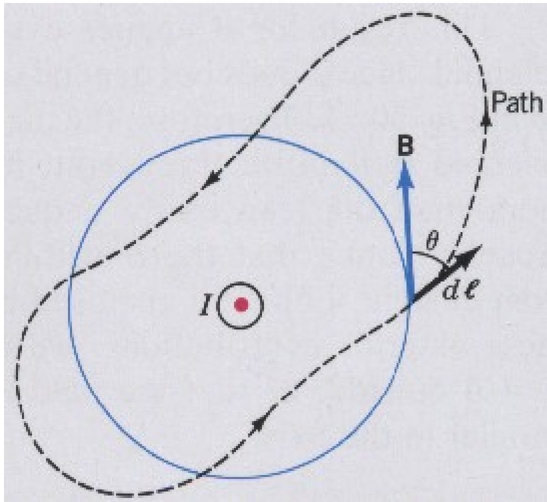


Fig.30.15

$\boxed{\text{安培定律}}\Rightarrow \oint \vec{B}\cdot d\vec{\ell}=\mu_0 I$

(考慮任意封閉路徑)

注意：
- I 為流過封閉路徑包圍的截面淨電流。
- I 需穩流且為非磁化物質才成立。
- I 可為帶電粒子束(a beam of charged particles)。
- B並非封閉路徑內的電流貢獻，而是所有鄰近電流的貢獻。
- 封閉路徑(或積分路徑)的選取需考慮磁場的分佈及電流流動的幾何形狀。

Example 30.5 An infinite straight wire of radius R carries a current I

$$For\ r > R \Rightarrow \oint \vec{B}\cdot d\vec{\ell} = B\oint d\ell = \mu_0 I$$

$$\Rightarrow B(2\pi r) = \mu_0 I \Rightarrow B = \frac{\mu_0 I}{2\pi r}$$

$$For\ r < R \Rightarrow B(2\pi r) = \mu_0 \frac{\pi r^2}{\pi R^2} I$$

$$\Rightarrow\ B = \frac{\mu_0 I r}{2\pi R^2}$$

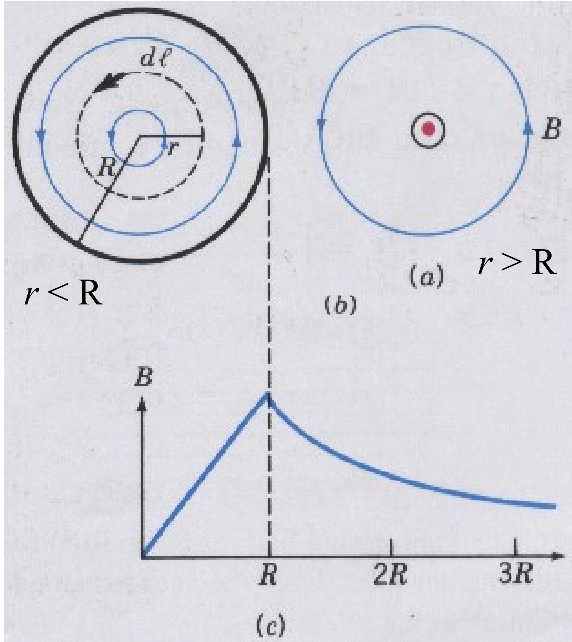


Fig.30.16

Example 30.6 An ideal infinite solenoid carries a current I

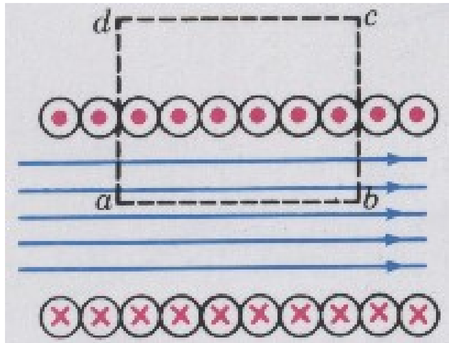


Fig.30.17

$$\oint \vec{B}\cdot d\vec{\ell} = \int_a^b \vec{B}\cdot d\vec{\ell} + \int_b^c \vec{B}\cdot d\vec{\ell} + \int_c^d \vec{B}\cdot d\vec{\ell} + \int_d^a \vec{B}\cdot d\vec{\ell}$$

$(\because$ 管外$\vec{B} = 0)$ $(\because \vec{B} \perp d\vec{\ell} \Rightarrow \int \vec{B}\cdot d\vec{\ell} = 0)$ *(note: n=N/L)*

$$\oint \vec{B}\cdot d\vec{\ell} = \int_a^b \vec{B}\cdot d\vec{\ell} = B\int_0^L d\ell = \mu_0 nLI \Rightarrow BL = \mu_0 nLI \Rightarrow B = \mu_0 nI$$

Example 30.7 An toroidal coil (with N turns) carries a current I

$$\oint \vec{B}\cdot d\vec{\ell} = B\oint d\ell = \mu_0 NI$$

$$\Rightarrow B(2\pi r) = \mu_0 NI \;\Rightarrow B = \frac{\mu_0 NI}{2\pi r}$$

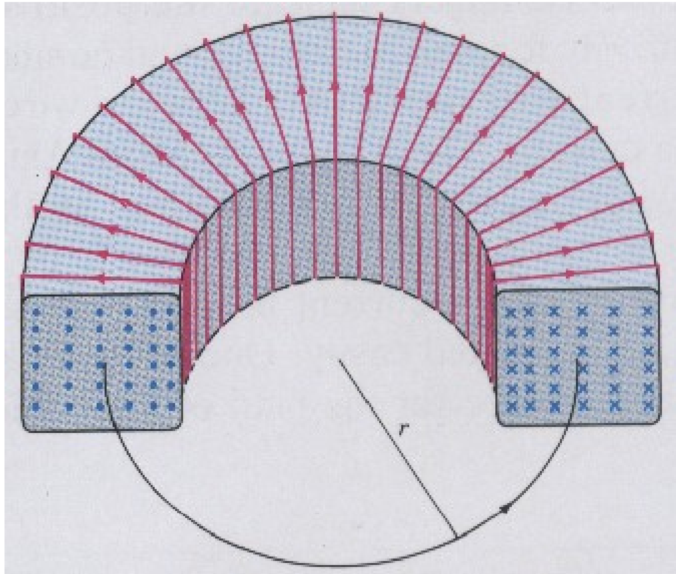
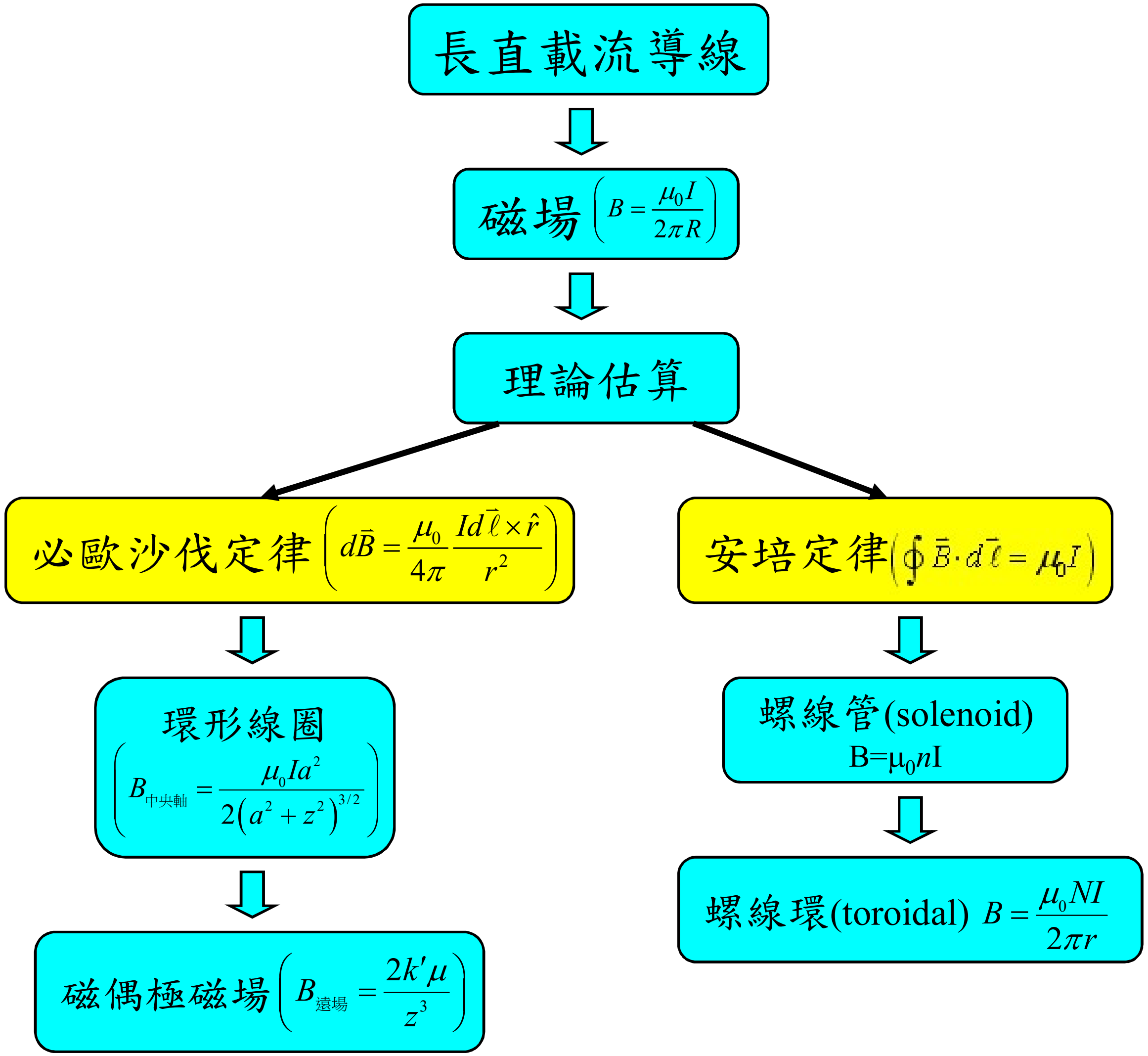


Fig.30.18

注意 $\Rightarrow \begin{cases} \text{管內磁場為非均勻。} \\ \text{管外磁場為零。} \end{cases}$

An unusual magnet at Lawrence Livermore Labs which is designed as part of a scheme to confine a hot plasma (ionized gas) in experiments for harnessing the energy released by the fusion of nuclei.

本章單元重要觀念發展脈絡彙整



習 題

- 教科書習題 (p.618~p.623)

  Exercise: 1,11,13,17,23,25,29,35,37,39,49

- 基本觀念問題：

  1.請說明必歐沙伐定律與安培定律。