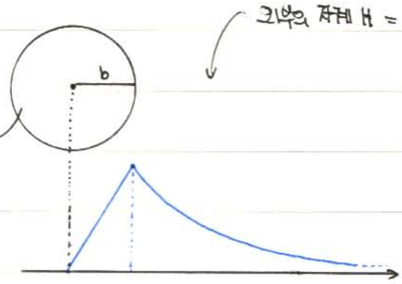
(식 5-10) $\oint \mathbb{H} \cdot d\mathbb{l} = nI$ by $\mathbb{B} = \mu_0 \mathbb{H}$

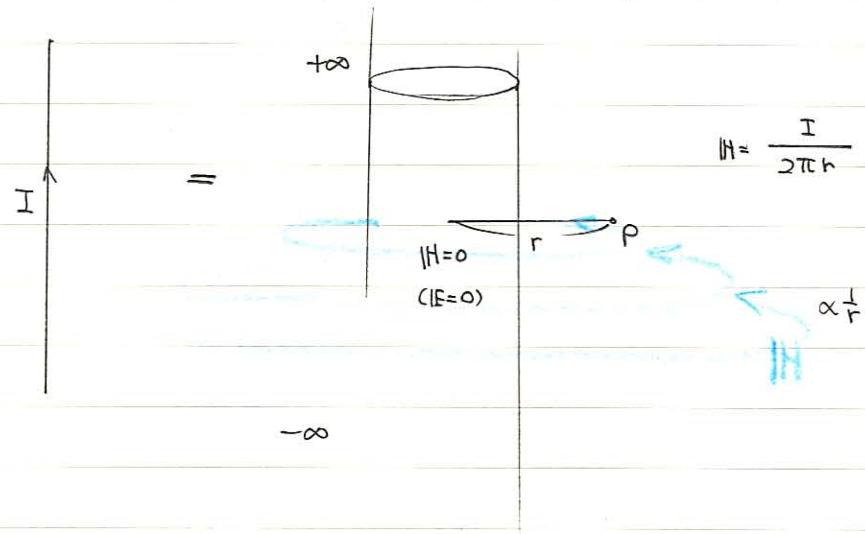
$$\oint \mathbb{B} \cdot d\mathbb{l} = \mu_0 n I$$

if) $n = 1$ 이면, $\oint \mathbb{B} \cdot d\mathbb{l} = \mu_0 I.$

외부의 자계 $H = \frac{I}{2\pi r}$

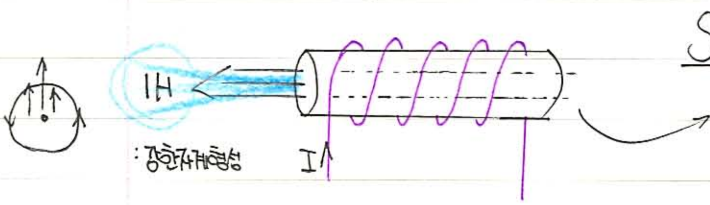


내부 $H = \frac{rI}{2\pi b^2}$



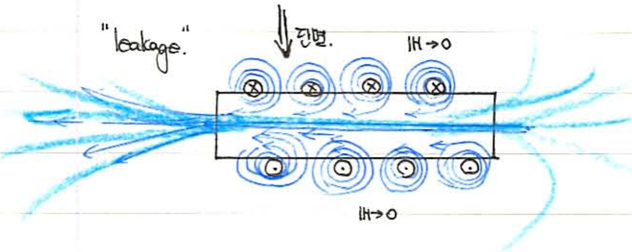
$$\mathbb{H} = \frac{I}{2\pi r} \quad [AT/m]$$

실제는 큰 IH를 얻기 위해서



Solenoide

강자성체, → 자화 → 자계형성



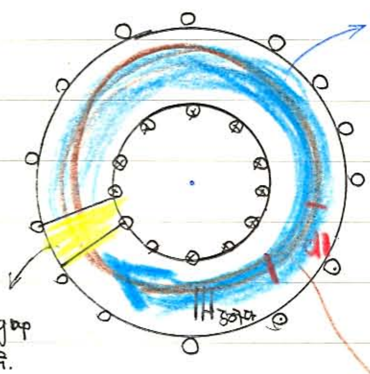
권선수 : 코일을 감은 횟수. N turns

102p. (예제 5-2) torodidal. 에 의한 자계.

Coil의 권수 = N

전류 I

자계 IH = ?



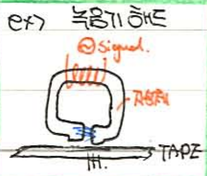
by Amperes Law
(주회…)

$\oint \mathbb{H} \cdot dl = nI$

폐곡.

A=1. 이라하자.

ex) 녹음기 헤드



$\oint \mathbb{H} \cdot dl = I$

$= \oint H \cdot dl \cos\theta$

$= \oint H\, dl \cos 0°$

$= \oint H \cdot dl$

Next≫

N

$$= H \oint dl$$

폐 Loop (closed Loop) 의 길이.

☆ 원통좌표계.

$$= H \cdot 2\pi r$$

$\therefore$ $H \cdot 2\pi r = NI$ (N의 권선수)

ⓒ> 직선전류 $H = \frac{I}{2\pi r}$.

$\therefore$ $H = NI / 2\pi r$ → 전체에 대한 H.

toroidal에 의한 자계.

이제, 단위길이당 권선수 = N(총 권선수) / 둘레(길이) = n.

$\therefore$ $H = nI$. [AT/m]

↳ '단위길이당 N

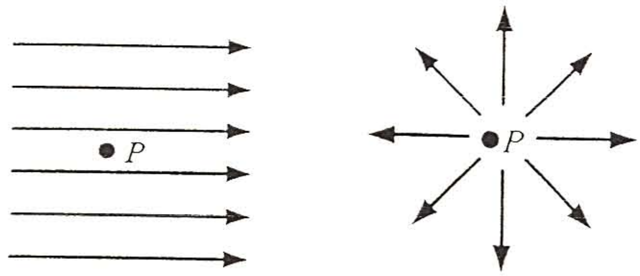
$H = \frac{NI}{2\pi r}$ 시계방향으로 회전 하는 방향

표현방법

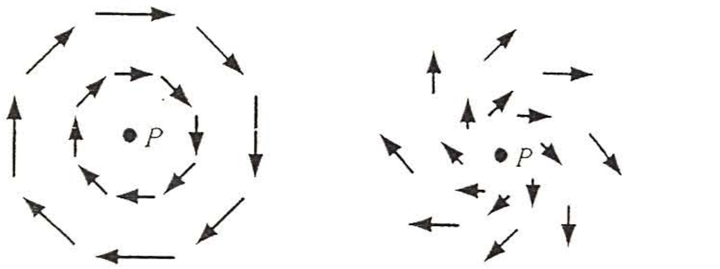
회전하는 벡터의 표현. ⇝ Circulation - 2.8.~9.

2-8, 9 Vector Circulation, Stoke's Theorem

"Del cross H."
or
"Curl H."



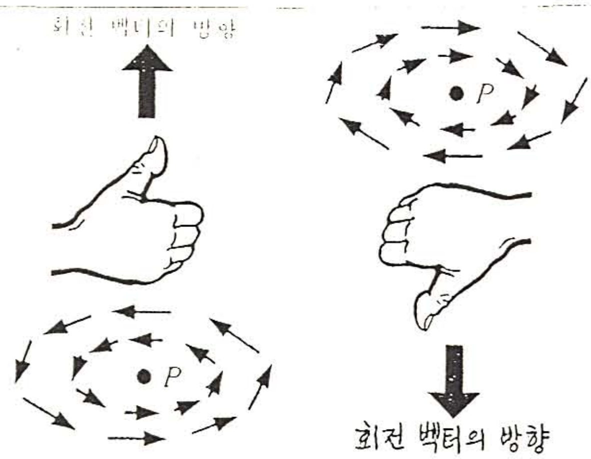
(a) 발산과 회전이 모두 0인 경우 ①　　(b) 회전만 0인 경우 ②



(c) 발산만 0인 경우③　　(d) 발산과 회전이 모두 0이 아닌 경우 ④

그림 24 벡터의 분류

① $\nabla \cdot A = 0$, $\nabla \times A = 0$
② $\nabla \cdot A \neq 0$, $\nabla \times A = 0$
③ $\nabla \cdot A = 0$, $\nabla \times A \neq 0$
④ $\nabla \cdot A \neq 0$, $\nabla \times A \neq 0$



(b) 시계반대방향의 회전　　(c) 시계방향의 회전

Stoke's Theorem

폐곡선 적분

식 2-103)

$$\oint_L \mathbb{A}\cdot d\mathbb{l} = \int_S \nabla\times\mathbb{A}\cdot d\mathbb{S} \qquad (2\text{-}103)$$

회전 : Circulation.

폐곡면. ex) pizza.

"폐곡선이 만드는 면적"

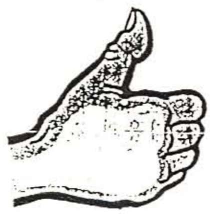
폐곡선 선적분 $\oint \mathbb{H}\cdot d\mathbb{l}$ = 폐곡선이 만드는 면적적분. $\int \nabla\times\mathbb{H}\cdot ds$

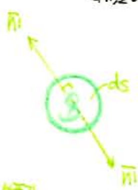
회전

(즉 H가 회전하고 있다.)

cf> $\int \nabla\cdot\mathbb{A}\, dv = \oint \mathbb{A}\cdot ds$ 체적적분 면적분 폐곡"면". ex) 수박.

— Divergence Theorem





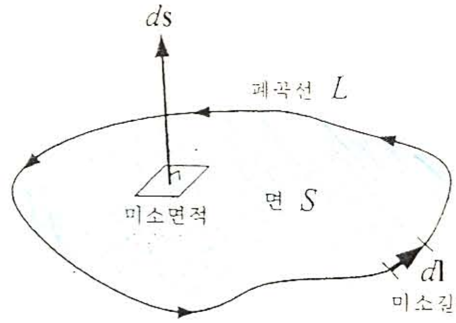


그림 22 Stokes 정리에서 면적벡터 ds와 길이벡터 dl의 방향 정의

Report>

(1). 다음 vector의 Curl을 구하라.

(a). $\mathbb{S} = xz\,\bar{x} + z^2yz\,\bar{z}$

(b). $\mathbb{T} = \sin\theta\,\bar{r} + r^2\,\bar{\phi}$

(c). $\mathbb{P} = \bar{R} + R\sin\theta\,\bar{\theta} + \cos\phi\,\bar{\phi}$

$$\oint \mathbb{H}\cdot d\ell = \int \nabla\times\mathbb{H} \cdot ds$$

"Cross Product."

표2-1)

$\frac{1}{h_1h_2h_3}\left(\frac{\partial}{\partial u_1}\overline{u_1}+\frac{\partial}{\partial u_2}\overline{u_2}+\frac{\partial}{\partial u_3}\overline{u_3}\right)$

직각좌표계) $\nabla\times\mathbb{A} = \left(\frac{\partial}{\partial x}\overline{x}+\frac{\partial}{\partial y}\overline{y}+\frac{\partial}{\partial z}\overline{z}\right)\times\left(A_x\overline{x}+A_z\overline{y}+A_z\overline{z}\right)$

원통좌표계) $\nabla\times\mathbb{A} = \left(\frac{\partial}{\partial r}\overline{\mathbb{r}}+\frac{1}{r}\frac{\partial}{\partial\phi}\overline{\phi}+\frac{\partial}{\partial z}\overline{z}\right)$

구) $\nabla\times\mathbb{A} = \left(\frac{\partial}{\partial R}\overline{\mathbb{R}}+\frac{1}{R}\frac{\partial}{\partial\theta}\overline{\theta}+\frac{1}{R\sin\theta}\frac{\partial}{\partial\phi}\overline{\phi}\right)$

(직각좌표) $= \begin{vmatrix} \overline{x} & \overline{y} & \overline{z} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ A_x & A_y & A_z \end{vmatrix}$

$$= \left(\frac{\partial A_z}{\partial y}-\frac{\partial A_y}{\partial z}\right)\overline{x} - \left(\frac{\partial A_z}{\partial x}-\frac{\partial A_x}{\partial z}\right)\overline{y} + \left(\frac{\partial A_y}{\partial x}-\frac{\partial A_x}{\partial y}\right)\overline{z}$$

$\equiv$ Curl. "Vector"

$\text{Curl}\,\mathbb{A} = \nabla\times\mathbb{A}$

cf) $\nabla\cdot\mathbb{A} \to$ scalar

$\nabla\times\mathbb{A} \to$ vector

$\nabla f \to$ vector.

(2-95, 96 식) 61p.

N°

$\nabla \times \mathbb{A} = 0$ $\mathbb{A}$ = 회전하지않는다.

$\neq 5$ $\mathbb{A}$는 5개만큼 회전.

예제. 2-15)

a) 원통좌표계 에서 $\vec{A} = (\frac{K}{r})\bar{\phi}$ $= A_\phi \bar{\phi}$ (단, K는 상수)

$\longrightarrow$ $\nabla \times \mathbb{A} = ?$ ①. $\mathbb{A}$가 회전하는가?

② 〃 〃 하면. 회전하는 크기는?

★ Cylindrical Coordinate.

$$\nabla \times \vec{A} = \frac{1}{r}\begin{vmatrix} \bar{r} & r\cdot\bar{\phi} & \bar{z} \\ \frac{\partial}{\partial r} & \frac{\partial}{\partial \phi} & \frac{\partial}{\partial z} \\ A_r & rA_\phi & A_z \end{vmatrix}$$

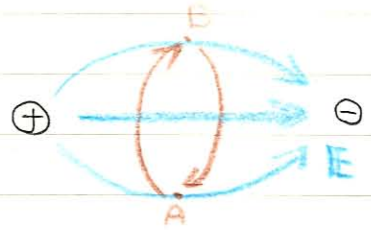
sol> $$\nabla \times \mathbb{A} = \frac{1}{r}\begin{vmatrix} \bar{r} & r\bar{\phi} & \bar{z} \\ \frac{\partial}{\partial r} & \frac{\partial}{\partial \phi} & \frac{\partial}{\partial z} \\ \underset{0}{\cancel{A_r}} & \underset{r(\frac{k}{r})}{r\cancel{A_\phi}} & \underset{0}{\cancel{A_z}} \end{vmatrix}$$

$$= (0 - \frac{\partial}{\partial z}K)\bar{r} - (0 - 0)\bar{\phi} + (\frac{\partial}{\partial r}K - 0)\bar{z}$$

$$= 0 - 0 + 0 = 0..$$

$\therefore$ $\nabla \times \mathbb{A}$, Curl $\mathbb{A}$ 는 '0' 즉. 회전하는 vector 가 아니다.

= Conservative Field (보존장)

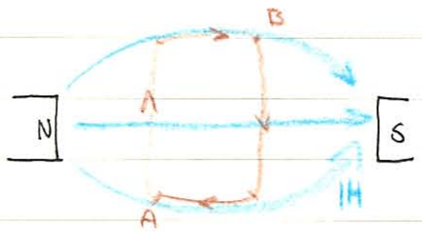


정전계.

$\oint \mathbb{E} \cdot dl = 0$

energy 가 보존된다 (보존장)

irrotation vector.



정자계

$\oint \mathbb{H} \cdot dl = 0$

예1. $\mathbb{A} = 2x\,\bar{x} + xz\,\bar{y}$ 의 회전여부 회전량을 구하라.

(직좌).

$$\nabla \times \mathbb{A} = \begin{vmatrix} \bar{x} & \bar{y} & \bar{z} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ \underset{=2x}{A_x} & \underset{xz}{A_y} & \underset{0}{A_z} \end{vmatrix} \rightarrow = \left(0 - \frac{\partial(xz)}{\partial z}\right)\bar{x} - \left(0 - \frac{\partial(2x)}{\partial z}\right)\bar{y} + \left(\frac{\partial(xz)}{\partial x} - \frac{\partial(2x)}{\partial y}\right)\bar{z}$$

$$= -x\,\bar{x} + 0 + (z - 0)\,\bar{z}$$

$$= -x\,\bar{x} + z\,\bar{z} \quad (\neq 0)$$

$\therefore$ 회전한다.

Report ☆

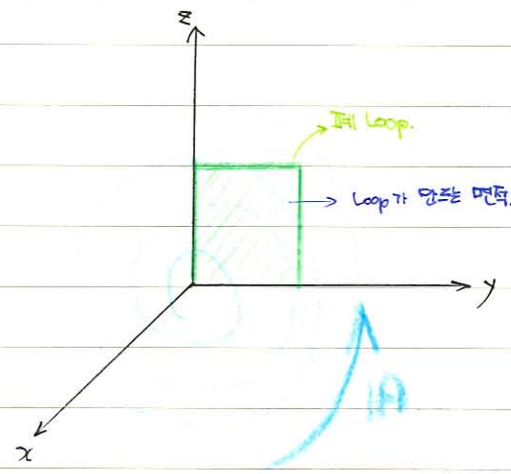
$\oint \mathbb{A} \cdot dl = \int \nabla \times \mathbb{A} \cdot ds$: Stoke's Theorem

이때, Stoke's Theorem 을 증명 or 풀이.

예1. $\mathbb{A} = (2xz + 3y^2)\,\bar{y} + (4yz^2)\,\bar{z}$ 인 Vector field 내에서

$x=0,\ y=z=1$ 인 면에서 Stoke's Theorem 이 성립함을 보여라.

N°



$$\oint \mathbb{A}\cdot d\mathbf{l} = \underbrace{\int \nabla\times\mathbb{A}\cdot d\mathbf{s}}_{①}$$

①.

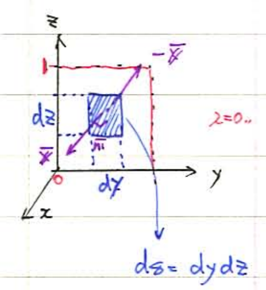
우선 $\nabla\times\mathbb{A} = \begin{vmatrix} \bar{x} & \bar{y} & \bar{z} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ 0 & (2xz+3y^2) & 4yz^2 \end{vmatrix} = \left\{ \frac{\partial(4yz^2)}{\partial y} - \frac{\partial(2xz+3y^2)}{\partial z} \right\}\bar{x}$

$$- \left\{ \frac{\partial(4yz^2)}{\partial x} - \frac{\partial(0)}{\partial z} \right\}\bar{y}$$

$$+ \left\{ \frac{\partial}{\partial x}(2xz+3y^2) - \frac{\partial}{\partial y}(0) \right\}\bar{z}$$

$$= (4z^2 - 2x)\bar{x} + 0\bar{y} + (2z)\bar{z}$$

↓



$$\int \underline{\{(4z^2 - 2x)\bar{x} + 2z\bar{z}\}} \cdot d\mathbf{s}$$

직각좌표계.

where $d\mathbf{s}$ → 직각으로 표현.

$d\mathbf{s} = ds\,\bar{n}$

$= dydz\,\bar{n}$

$= dydz\,\bar{x}$

$\therefore d\mathbf{s} = dydz\,\bar{x}$

$$\int_0^1 \{(4z^2 - \cancel{2x})\bar{x} + 2z\bar{z}\} \cdot dydz\,\bar{x}$$

(x)

단. x=0.

$$= \int_0^1 (4z^2\bar{x} + \underbrace{2z\bar{z}}_{\text{"0"}}) \cdot dydz\,\bar{x}$$

N°

$(\bar{x} \cdot \bar{x} = 1.)$

$$= \int_{0,\ x=0}^{1} 4z^2 \, dy dz .$$

(이중적분임을 명시하자).

$$= \int_0^1 \int_0^1 4z^2 \, dy \, dz \qquad \because \int_0^1 4z^2 y = \left| 4z^2 y \right|_{y=0}^{y=1} = 4z^2$$

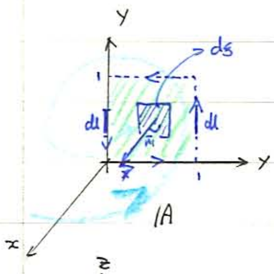
$$= \int_0^1 4z^2 \, dz = \left| \frac{4}{3} z^3 \right|_{z=0}^{z=1}$$

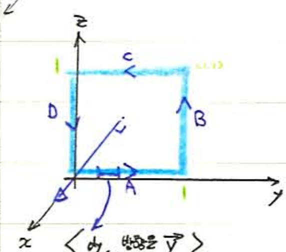
$$= \frac{4}{3} \quad (\neq 0)$$

$\therefore$ $\mathbb{A}$ 회전하고, 회전값은 '$\frac{4}{3}$'

070919 We.

070917 mon ~A10:43





⟨dy. 방향은 $\vec{y}$⟩

② 예제1. $\oint \mathbb{A} \cdot d\mathbb{l} = ?$

sol) $\oint \mathbb{A} \cdot d\mathbb{l} = \int_A \mathbb{A} \cdot d\mathbb{l} + \int_B \mathbb{A} \cdot d\mathbb{l} + \int_C \mathbb{A} \cdot d\mathbb{l} + \int_D \mathbb{A} \cdot d\mathbb{l}.$

① where. $\int_A \mathbb{A} \cdot d\mathbb{l} = \int \underbrace{\{(2xz + 3y^2)\,\bar{y} + (4yz^2)\,\bar{z}\}}_{\text{직각좌표계}} \cdot d\mathbb{l}.$

"$d\mathbb{l} = dy \cdot \bar{y}$"

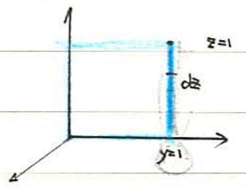
$$\int_A \mathbb{A} \cdot d\mathbb{l} = \int_{z=0,\ x=0} \{(\cancel{2xz}^{\,0} + 3y^2)\,\bar{y} + (\cancel{4yz^2}^{\,0})\,\bar{z}\} \cdot dy \ \bar{y}$$

$$= \int_{x=z=0} 3y^2 \cdot \bar{y} \cdot dy \ \bar{y}$$

$y^n = y^{n+1}/_{n+1}$

$$= \int_0^1 3y^2 \, dy = \left| y^3 \right|_0^1 = 1.$$

N



②

$$\int_B \mathbb{A}\cdot d\mathbb{l} = \int \left[(2xz+3y^2)\bar{y} + (4yz^2)\bar{z} \right]\cdot d\mathbb{l}$$

$\langle\, d\mathbb{l} = dz\cdot\bar{z} \,\rangle$

$$= \int_{\substack{z=0\sim1 \\ y=1 \\ x=0}} \left[(2\cancel{x}z + 3\overset{3\cdot1^2}{\cancel{y}^2})\bar{y} + (4\overset{1}{\cancel{y}}z^2)\bar{z} \right]\cdot dz\,\bar{z}$$

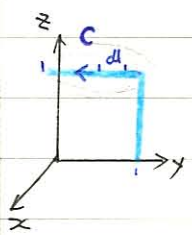
$$= \int_0^1 (3\cancel{\bar{y}} + 4z^2\bar{z})\cdot \boxed{dz\,\bar{z}}$$

'0'

$$= \int_0^1 4z^2\cdot dz$$

$$= \left| 4\cdot\frac{z^3}{3} \right|_0^1 = \frac{4}{3}$$

z방향으로 향한 양.



③

$$\int_C \mathbb{A}\cdot d\mathbb{l} = \int \left[(2xz+3y^2)\bar{y} + (4yz^2)\bar{z} \right]\cdot d\mathbb{l}$$

$\langle\, d\mathbb{l} = dy\,(-\bar{y}) \,\rangle$

$$= \int \left\{ (2xz+3y^2)\bar{y} + \overset{'0'}{\cancel{(4yz^2)\bar{z}}} \right\}\cdot dy\,(-\bar{y})$$

$$= -\int_{\substack{x=0 \\ y=1\sim0 \\ z=1}} (2\overset{0}{\cancel{x}}z + 3y^2)\,dy$$

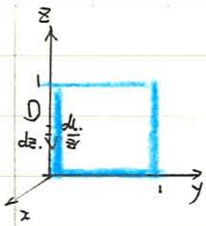
$$= -\int_0^1 3y^2\,dy = -\left| y^3 \right|_0^1$$

$$= -1$$

$-y$ 방향으로 향하는. 양.

→ 0109 해결.

N°



④ $\int_D \mathbb{A} \cdot d\mathbb{l} = \int [\,(2xz + 3y^2)\,\overline{y} + (4yz^2)\,\overline{z}\,\} \cdot d\mathbb{l}$

$d\mathbb{l} = dz \cdot (-\overline{z})$

$$= \int_{\begin{cases} z = 1 \sim 0 \\ y = 0 \\ x = 0 \end{cases}} \{\, (2xz + 3y^2)\,\overline{y} + (4yz^2)\,\overline{z} \,\} \cdot dz\,(-\overline{z})$$

$= 0.$

$\therefore \oint \mathbb{A} \cdot d\mathbb{l} = 1 + \frac{4}{3} + (-1) + 0 = \frac{4}{3}_{/\!/} = \int \nabla \times \mathbb{A} \cdot ds$

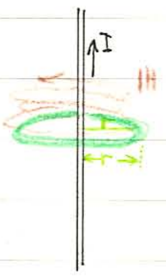
Report. (4). $\mathbb{A} = x^2\,\overline{x} + 3y\,\overline{y} + yz\,\overline{z}$ 인

Vector Field 내 에서 $\begin{cases} z = 0 \\ y = x = 1 \end{cases}$ 인 면에서

Stoke's theorem 계산하라.

Stokes's theorm

$$\int \nabla \times \mathbb{H} \cdot ds = \oint \mathbb{H} \cdot dl$$



by Ampere's Circuital Law.

다음 시간 중 중간고사.

$H = I / 2\pi r$ 크기. 방향은 x.

I = 일정하므로. H = 정자계

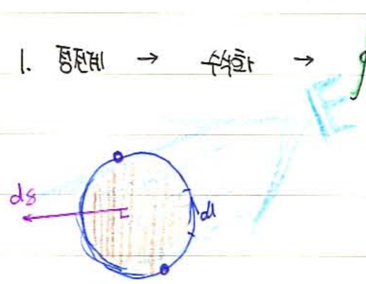
$\mathbb{H} = I / 2\pi r$ (반시계방향으로 회전하고. 이 회전은 평면하고. 도는 직각 (by 오른손법칙))

vector

→ 수식화 by "Bio - Savart."

* Stokes's Theorem 의 이용의 예

1. 정전계 → 수식화 → $\oint \mathbb{E} \cdot dl = 0$ (식 3-7)



여기서 E는 회전하는가?

by Stokes's Theorem.

$$\oint \mathbb{E} \cdot dl = \int \nabla \times \mathbb{E} \; ds = 0$$

$\therefore \nabla \times \mathbb{E} = 0$ 이므로 E는 회전하지 않는다.

$\oplus \longrightarrow \ominus$

(o)

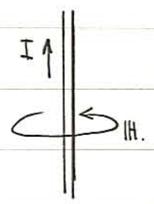
$\oplus \rightleftarrows \ominus$ 갔다가 돌아온다.

(x).

2. 정자계 → $\oint \mathbb{H} \cdot d\mathbb{l} = 0$ (by 자석)

$\oint \mathbb{H} \cdot d\mathbb{l} = nI$ (by 전류)

과연 H는 회전하는가?



$$\oint \mathbb{H} \cdot d\mathbb{l} = \int \nabla \times \mathbb{H} \cdot ds = nI$$

$$\therefore \nabla \times \mathbb{H} \neq 0$$

∴ H는 회전한다. 그런데 회전량을 모른다.

→ 계산에 의한 수식화.

$$\oint \mathbb{H} \cdot d\mathbb{l} = nI \quad , n = 1.$$

$$\oint \mathbb{H} \cdot d\mathbb{l} = I. \text{ (총전류)}$$

$$I = \oint \mathbb{J} \cdot ds \qquad (\mathbb{J} : \text{전류밀도})$$

면적적분..

$$\therefore \underbrace{I = \oint \mathbb{H} \cdot d\mathbb{l}}_{\text{Ampere's Circuital Law 의 적분형.}} = \int \nabla \times \mathbb{H} \cdot ds = \oint \mathbb{J} \cdot ds$$

단골.

《대학원 시험》

"미분형을 구하고 설명하라."

Vector. 크기. 방향 표현

$$\therefore \underbrace{\nabla \times \bar{\mathbb{H}} = \bar{\mathbb{J}}}_{\text{Ampere's Circuital Law 의 미분형.}} \qquad (5-61)$$

cf>. $\nabla \times \mathbb{H} = 0$

: H = 정자계, 보존장.

5-3. Vector Potential

Bio - Savart's Law.

◦ 정전계 : $\oint \mathbb{E}\cdot dl = 0$: $\mathbb{E} = -\nabla \underset{\sim}{V}$: V= 전위, Electric Potential.

$= Q/4\pi\varepsilon_0 R$

Scalar potential.

◦ 정자계 ─ 자석 : $\oint \mathbb{H}\cdot dl = 0$: $\mathbb{H} = -\nabla \underset{\sim}{U}$: U = 자위. magnetic Potential.

$= m/4\pi\mu_0 R$

╲ 전류 : $\underbrace{\oint \mathbb{H}\cdot dl = nI}_{\neq 0}$: $\mathbb{H} = ?$ Vector Potential.. → Vector Potential

$= \frac{1}{\mu_0}(\nabla\times\mathbb{A})$: $\mathbb{A}$ = Vector Potential

자속밀도 $\mathbb{B}$ => $\nabla\cdot\mathbb{B} = 0$ (항상연속)

항상 연속인 vector는 임의의 vector의 회전으로 표시할 수 있다.

↳ $\mathbb{B} = \nabla\times\mathbb{A}$ (5-14 식)

$\nabla\times\mathbb{H} = \mathbb{J}$

$\mathbb{B} = \mu\mathbb{H}$

$\therefore\ \mathbb{J} = \nabla\times\mathbb{H} = \nabla\times\left(\frac{\mathbb{B}}{\mu}\right) = \nabla\times\frac{(\nabla\times\mathbb{A})}{\mu} = \frac{1}{\mu}(\nabla\times\nabla\times\mathbb{A})$

$\therefore\ \mathbb{J} = \frac{1}{\mu}(\underset{\sim\sim\sim}{\nabla\times\nabla\times}\mathbb{A})$ (5-15)

where, 부록. $\nabla\times\nabla\times\mathbb{A} = \nabla\,(\underset{\sim}{\nabla\cdot\mathbb{A}}) - \nabla^2\mathbb{A}$

$\mathbb{A}$의 발산. $\mathbb{A}$는 연속. $\longrightarrow \nabla\cdot\mathbb{A} = 0$

$= -\nabla^2\mathbb{A}$

N°

$$\therefore \quad \mathbb{J} = \frac{1}{\mu}(-\nabla^2 \mathbb{A})$$

$$\underline{\nabla^2 \mathbb{A} = -\mu \mathbb{J}}$$

여기서, $\mathbb{A} = ?$

$\rightarrow \nabla \times \mathbb{A} \longrightarrow \mathbb{B}$

$\rightarrow \mathbb{B} = \mu \mathbb{H} \rightarrow \mathbb{H}$

15-20) Vector, Poisson's equation.

cf> 전계구하는법.

1. 쿨롱법칙
2. $\mathbb{E} = -\nabla \bar{V}$
3. $\oint \mathbb{E} \cdot d\mathbb{S} = Q/\varepsilon_0$

아르즈 ~> 톤톤 (아이버스)
(수정 테이프 × 5개
리필 20개)

4. Poisson's & Laplace eq. → 대학용
5. 전기영상법

정전계에서

$$\nabla \cdot \mathbb{E} = \rho_v/\varepsilon_0 \quad , \quad \mathbb{E} = -\nabla \bar{V}$$

$$\therefore \nabla \cdot \mathbb{E} = \nabla \cdot (-\nabla \bar{V}) = \rho_v/\varepsilon_0$$

$$= -\nabla^2 \bar{V} = \rho_v/\varepsilon_0$$

$$\therefore \star\ \nabla^2 \bar{V} = -\rho_v/\varepsilon_0$$: Scalar Poisson's eq.

$$\bar{V} = Q/4\pi\varepsilon_0 R = 1/4\pi\varepsilon_0 \int \frac{\rho_v}{R}\, dv$$: Vector Poisson's eq.

$$\underline{\nabla^2 \mathbb{A} = -\mu \mathbb{J}}$$

$$\begin{cases} \nabla^2 A_x \cancel{\bar{x}} = -\mu J_x \cancel{\bar{x}} \\ \nabla^2 A_y \cancel{\bar{y}} = -\mu J_y \cancel{\bar{y}} \\ \nabla^2 A_z \cancel{\bar{z}} = -\mu J_z \cancel{\bar{z}} \end{cases}$$

$$\therefore \begin{cases} A_x = -\mu/4\pi \int \frac{J_x}{R}\, dv \\ A_y = -\mu/4\pi \int J_y/R \, dv \\ A_z = -\mu/4\pi \int \frac{J_z}{R}\, dv \end{cases}$$

$$\therefore \ \mathbb{A} = A_x \bar{x} + A_y \bar{y} + A_z \bar{z}$$

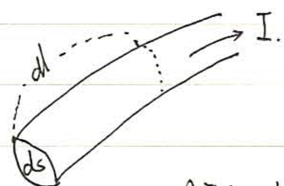
$$\mathbb{A} = \frac{\mu}{4\pi} \int \frac{\mathbb{J}}{R}\, dv \qquad (5\text{-}22)$$

= Vector Potential.

$$\mathbb{E} = -\nabla \bar{V}, \quad \bar{V} = \frac{1}{4\pi\varepsilon_0} \int \frac{\rho_v}{R}\, dv \quad : \text{Scalar potential}$$

전류밀도

$$\mathbb{B} = \nabla \times \mathbb{A}, \quad \mathbb{A} = \frac{\mu}{4\pi} \int \frac{\mathbb{J}}{R}\, dv \quad : \text{Vector potential} \quad (5\text{-}22)$$



여기서 $dv = ds\, dl$

$$\mathbb{J} \cdot dv = \mathbb{J}\, ds\, dl = I\, dl$$

$$\therefore \ \mathbb{A} = \frac{\mu}{4\pi} \oint \frac{I}{R}\, dl \quad (5\text{-}26)$$: 총전류 I에 의한 Vector Potential

이제 $\nabla \times \mathbb{A} = \mathbb{B}$ 를 계산해서 $\mathbb{B}$를 구한다.

$$\mathbb{B} = \nabla \times \mathbb{A} = \nabla \times \left(\frac{\mu}{4\pi} \oint \frac{I}{R}\, dl \right) = \nabla \times \left(\frac{\mu I}{4\pi} \oint \frac{dl}{R} \right)$$

N°

$$= \frac{\mu I}{4\pi} \oint \nabla \times \left(\frac{dl}{R} \right) \qquad (5-29)$$

$$\left(\nabla\frac{1}{R} = -\frac{\bar{IR}}{R^2} = -\frac{IR}{R^3} \right)$$

where. $\nabla \times \left(\frac{dl}{R} \right) = \frac{1}{R} (\cancel{\nabla \times dl})^{0} + \left(\nabla \frac{1}{R} \right) \times dl$

회전x.

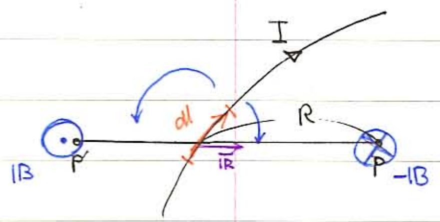
$\nabla \times (G\,A)$

$= G(\nabla \times A) + (\nabla G) \times A$

$$\therefore \; B = \frac{\mu I}{4\pi} \oint \frac{-IR \times dl}{R^3}$$

$$B = \frac{\mu I}{4\pi} \oint \frac{dl \times IR}{R^3} \qquad (5-31)$$

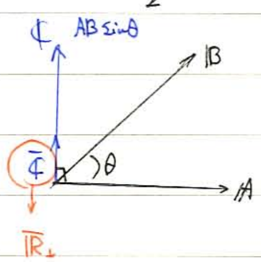
총전류 I에 의한 자속밀도 IB를 구하는 식.



이때 $B = \mu H$ 이므로, $H = \frac{B}{\mu}$.

$$\therefore \; H = \frac{I}{4\pi} \oint \frac{dl \times IR}{R^3}$$

$A \times B = A \cdot B \cdot \sin\theta \cdot \bar{\Phi}$



$$= \frac{I}{4\pi} \oint \frac{dl \times \bar{IR}}{R^2} = \frac{I}{4\pi} \oint \frac{dl \cdot 1 \cdot \sin\theta \; \bar{\Phi}}{R^2}$$

$$= \frac{I}{4\pi} \oint \frac{dl \cdot 1 \cdot \sin\theta \; \bar{IR}_\perp}{R^2}$$

크기 방향

$$\therefore \; H = \frac{I}{4\pi} \oint \frac{dl \cdot \sin\theta}{R^2} \; \bar{IR}_\perp \quad [AT/m]$$

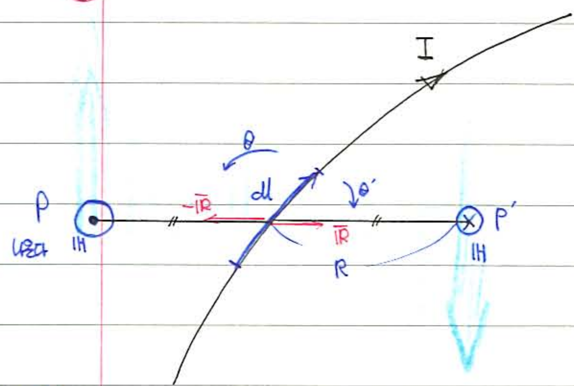
Bio-Savart's Law.

where, $\bar{IR}_\perp$ = Vector dl 과 IR 가 만드는 평면에 수직이고 크기가 1 인 unit Vector.

수식과 그림과 일치시켜라 ↓ 습관

END. → 071001 MON. ~1044 AM

Bio-Savart's Law.



(5-30)
Zoop?. 중요

$\nabla\left(\frac{1}{R}\right)$

$= -\frac{\mathbb{R}}{R^2} = -\frac{\mathbb{R}}{R^3}$

※ 전체 구하는 식과의 차이

$$\mathbb{E} = \frac{1}{4\pi\varepsilon_0} \int \frac{\rho_v}{R^2}\, dv$$

$$\mathbb{H} = \frac{I}{4\pi} \oint \frac{dl \ \sin\theta}{R^2} \ \mathbb{R}_\perp$$

μ_0가 없다.

cf. 가우스.
쿨롱법칙

Ampere's Law.
Bio-Savart Law.

→

$H = \frac{I}{2\pi r}$

$H = ?$

071008 MON →

$$\mathbb{B} = \nabla \times \mathbb{A}$$

$$\mathbb{B} = \mu \mathbb{H}$$

-+> $\mathbb{E} = -\nabla V$ ~ "scalar potential."

$$\therefore \mathbb{H} = \frac{1}{\mu} (\nabla \times \mathbb{A})$$

$$\mathbb{A} = \frac{\mu I}{4\pi} \oint \frac{dl}{R} \quad (5\text{-}26)$$

(5-31) $$\therefore \mathbb{B} = \frac{\mu I}{4\pi} \oint \frac{dl \times \hat{\mathbb{R}}}{R^2} = \frac{\mu I}{4\pi} \oint \frac{dl \times \mathbb{R}}{R^3} \quad (5\text{-}31)$$

Bio-Savart's Law

$$\therefore \mathbb{H} = \frac{I}{4\pi} \oint \frac{dl \times \hat{\mathbb{R}}}{R^2} = \frac{I}{4\pi} \oint \frac{dl \times \mathbb{R}}{R^3}$$

<+> 정전계. $\mathbb{E} = \frac{1}{4\pi\varepsilon_0} \int \frac{\rho_v}{R^2} dv$

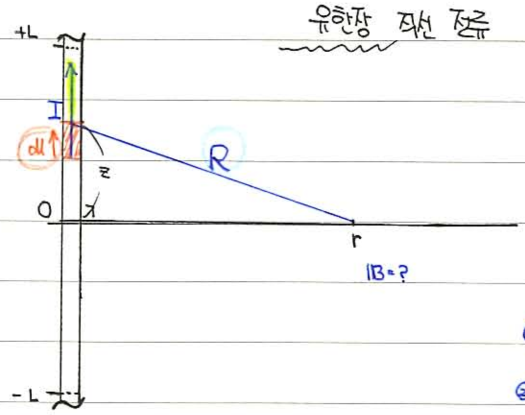
「잘 알아두도록」

전계 $\mathbb{E}$ (ε_0)	↔	$\mathbb{H}$ 자계 ($\cancel{\mu}$)
전속 $\mathbb{D}$ ($\cancel{\varepsilon_0}$)	↔	$\mathbb{B}$ 자속 (μ)
↓		↓
$\mathbb{D} = \varepsilon \mathbb{E}$		$\mathbb{B} = \mu \mathbb{H}$

「앙페어 주회법칙보다 쉽나 안쉽나?」

300p. 예제 5-3.

유한장 직선 전류



원통좌표계

$\mathbb{B} = ?$

$\mathbb{B} = \nabla \times \mathbb{A}.$

① $\mathbb{A} \rightarrow \mathbb{B} = \nabla \times \mathbb{A}..$ 〉 풀어서 비교.

② Biot - Savart's Law.

수식 그림으로 표현할 줄 아냐!

예> 무한장 직선 전류에 의한 자계.

(앙페어 주회법칙)

$\oint \mathbb{H} \cdot dl = nI$

$H = \frac{I}{2\pi r}$

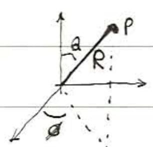
Sol.., 자유공간!! μ_0.

Ⓘ

$$\mathbb{A} = \frac{\mu_0 I}{4\pi} \oint \frac{dl}{R}$$

where, 원통좌표계, (∵ 자계는 원통방향,
by 오른손방향)

구좌표계.



$$\begin{cases} dl = dz\ \hat{z} \\ R = \sqrt{z^2 + r^2} \end{cases}$$

$\Downarrow$

$$\therefore \mathbb{A} = \frac{\mu_0 I}{4\pi} \int_{-L}^{+L} \frac{1}{\sqrt{z^2 + r^2}}\, dz \cdot \hat{z}$$

Scalar → 적분가능.

공업수학 적분공식.

$$\left(\text{where, } \int \frac{1}{\sqrt{x^2 \pm a^2}}\, dx = \ln \left(x + \sqrt{x^2 \pm a^2} \right) \right)$$

$$= \frac{\mu_0 I}{4\pi} \left| \ln\left(z + \sqrt{z^2 + r^2}\right) \right|_{-L}^{+L}$$

$$= \frac{\mu_0 I}{4\pi} \ln\left(\frac{L + \sqrt{L^2 + r^2}}{-L + \sqrt{L^2 + r^2}} \right) \bar{z}$$

$$= \frac{\mu_0 I}{4\pi} \ln\left(\frac{\sqrt{L^2 + r^2} + L}{\sqrt{L^2 + r^2} - L} \right) \bar{z} = A_z \bar{z}$$

전류방향과 같다.

z방향의 크기 A_z.

$\mathbb{B} = \nabla \times \mathbb{A}$ 이므로,

$$\underbrace{\nabla \times \mathbb{A}}_{\text{원통좌표계.}} = \frac{1}{r} \begin{vmatrix} \bar{r} & r\cdot\bar{\phi} & \bar{z} \\ \frac{\partial}{\partial r} & \frac{\partial}{\partial \phi} & \frac{\partial}{\partial z} \\ \cancel{A_r} & \cancel{rA_\phi} & A_z \end{vmatrix}$$

$$= \frac{1}{r} \left\{ \bar{r}\left(\frac{\partial}{\partial \phi} A_z - \frac{\partial}{\partial z} \cdot 0 \right) - r\bar{\phi}\left(\frac{\partial}{\partial r} A_z - 0 \right) + \bar{z}\,(0 - 0) \right]$$

$$= \frac{\bar{r}}{r} \cdot \left(\frac{\partial}{\partial \phi} A_z \right) - \bar{\phi}\left(\frac{\partial}{\partial r} A_z \right)$$

$= \phi$ 편미분이므로 '0' $- \bar{\phi} \left\{ \frac{\partial}{\partial r} \left(\frac{\mu_0 I}{4\pi} \ln\left(\frac{\sqrt{L^2 + r^2} + L}{\sqrt{L^2 + r^2} - L} \right) \right) \right)$

① 차이점을

알아라!!!

(5-34) $$= \frac{\mu_0 \cdot I \cdot L}{2\pi r \sqrt{L^2 + r^2}} \bar{\phi} = \mathbb{B}$$

(5-35)

$$\therefore \mathbb{H} = \frac{I \cdot L}{2\pi r \sqrt{L^2 + r^2}} \bar{\phi} \quad [AT/m]$$

cf.> Ampere's Circuital. Law를 이용해서,

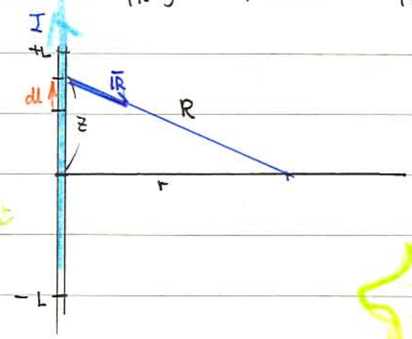
$H = \frac{I}{2\pi r}$ <방향X>

"길이 2L 인 전류에 의한 자계"

"길이=∞ 인 무한장 전류에 의한 자계 (L→∞)" → $\therefore \mathbb{H} = \frac{I}{2\pi r} \bar{\phi}$ [AT/m]

② Biot - Savart's Law 직접 이용.

$$\mathbb{B} = \frac{\mu I}{4\pi}\oint \frac{dl \times \hat{\mathbb{R}}}{R^2} = \frac{\mu I}{4\pi}\oint \frac{dl \times \mathbb{R}}{R^3}$$



좌표계 통일

〃 원통좌표계.

$$= \frac{\mu_0 I}{4\pi}\int_{-L}^{+L} \frac{dl \times \mathbb{R}}{R^3}$$

where, $\mathbb{R} = \mathbb{r} - \mathbb{z} = r\,\bar{\mathbb{r}} - z\,\bar{\mathbb{z}}$

$dl = dz\,\bar{\mathbb{z}}$

$\therefore\ dl \times \mathbb{R} = dz\,\bar{\mathbb{z}} \times (r\,\bar{\mathbb{r}} - z\,\bar{\mathbb{z}})$

$= dz\,\bar{\mathbb{z}} \times r\,\bar{\mathbb{r}} - (dz\,\bar{\mathbb{z}} \times z\,\bar{\mathbb{z}})$

$\vec{r\phi z\ r\phi z}$

$= r\,dz\,\bar{\phi} - \cancel{z\,dz\cdot 1\cdot 1\cdot \sin 0^\circ} \rightarrow 0$

$= r\,dz\,\bar{\phi}$

$R = \sqrt{z^2+r^2}\ ,\ R^3 = (\sqrt{z^2+r^2})^3$

$= (z^2+r^2)^{\frac{3}{2}}$

$$= \frac{\mu_0 I}{4\pi}\int_{-L}^{+L} \frac{r\,dz\,\bar{\phi}}{(z^2+r^2)^{\frac{3}{2}}}$$

$$= \frac{\mu_0 I}{4\pi}\int_{-L}^{+L} \frac{r}{(z^2+r^2)^{\frac{3}{2}}}\,dz\,\bar{\phi}$$

where,

$$\int \frac{1}{(x^2+a^2)^{\frac{3}{2}}}\,dx = \frac{x}{a^2(x^2+a^2)^{\frac{1}{2}}}$$

$$= \frac{\mu_0 I\cdot r}{4\pi}\int_{-L}^{+L} \frac{1}{(z^2+r^2)^{\frac{3}{2}}}\,dz\,\bar{\phi} = \frac{\mu_0 I\cdot r}{4\pi}\left|\frac{z}{r^2(z^2+r^2)^{\frac{1}{2}}}\right|_{-L}^{+L}\bar{\phi}$$

$$= \frac{\mu_0 I r}{4\pi}\left[\frac{L}{r^2(L^2+r^2)^{\frac{1}{2}}} - \left\{\frac{-L}{r^2((-L)^2+r^2)^{\frac{1}{2}}}\right\}\right]\bar{\phi}$$

$$= \frac{\mu_0 I r}{\cancel{4}\pi_{2}} \left[\frac{\cancel{2}L}{r^2 (L^2+r^2)^{\frac{1}{2}}} \right] \bar{\phi}$$

$$= \frac{\mu_0 \cdot I \cdot L}{2\pi r \sqrt{L^2+r^2}} \bar{\phi}$$

where, $L \to \infty$ 이면. (= 무한장 전류이면)

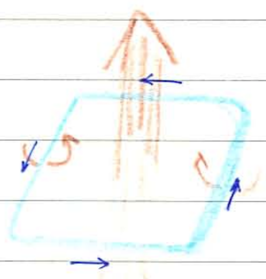
5-34)

$$\therefore \mathbb{B} = \frac{\mu_0 I}{2\pi r} \bar{\phi}$$

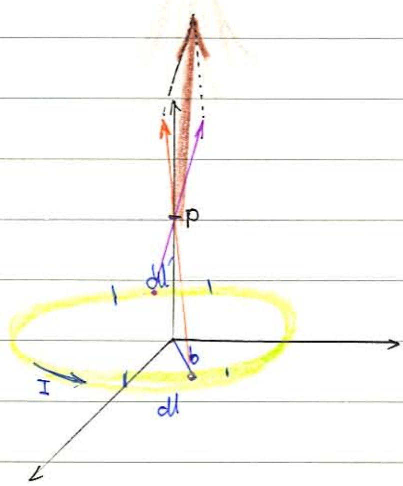
vs. 5-12)

$$\therefore \mathbb{H} = \frac{I}{2\pi r} \bar{\phi} \quad [AT/m]$$

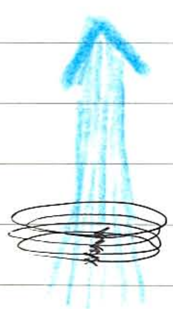
예제 5-4. 변형.



예제 5-5.



"Inductor"



전류에 의해 Energy 비축
(자계)

coil에 정상전류(DC) I가 흐르면,

H가 생긴다.
자계.

H는 coil 사이에 존재.

cf> 전계.

"Condenser"

전압에 의한 전계 비축

4. 정전용량.
"Capacitance"
⟨Capacitor, Condenser⟩

5-10. Inductance 유도용량. , Inductor.

도체 → $R = \bar{V}/I = \dfrac{\text{도체에서 두 점 간의 전위차}}{\text{전위차에 의한 전하 이동}}$

유전체 → $C = Q/V = \dfrac{\text{유전체로 격리된 도체의 전하량}}{\text{〃 도체의 전위차}}$

$L = ?/? = ?/I$

(자계 energy)

→ 07/008 MON

기말고사

☆ 중간고사,

4장 ~

전기, 자기

< ID = ID 법칙 >

Stoke 정리

~ 비오사바르,,

모범답안 → 내일 1.2교시

수업 반환.