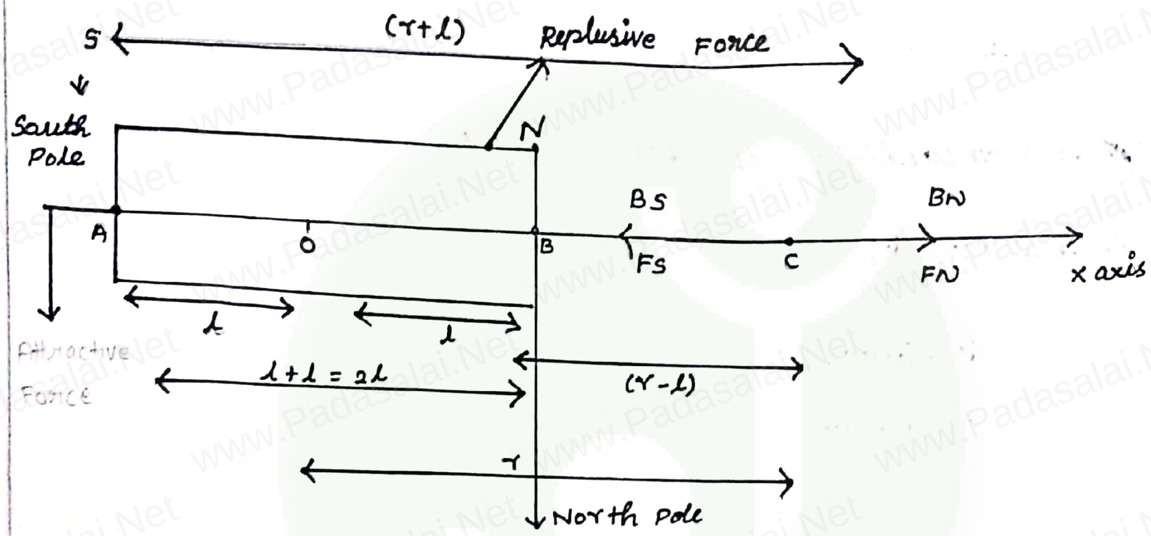
LESSON - 3

MAGNETISM AND MAGNETIC EFFECTS OF ELECTRIC CURRENT

1. Magnetic field due to an axis line in Magnetic dipole [BAR MAGNET]



S → South Pole

N → North Pole

O → center of Point

l → length

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F → Force

r → Distance

B → Magnetic field

BS → South Pole in Magnetic field

BN → North Pole in Magnetic field

FS → South Pole in Force

FN → North Pole in Force

C → Free space

q_m → Magnetic pole strength

SO → l

ON → l

SN = $l + l = 2l$

OC = r

NC ⇒ $(r-l)$

SC → $(r+l)$.

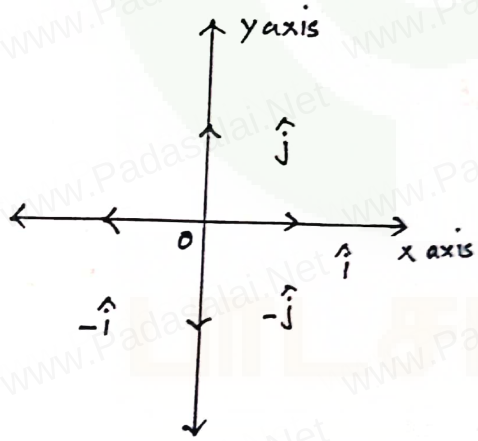
μ_0 → Permeability of free space

$\mu_0 \rightarrow 4\pi \times 10^{-7}$ H/m

H - henry.

M - Meter

$\mu_0 \rightarrow 4 \times 3.14 \times 10^{-7}$ H/m



REPULSIVE FORCE :-

$$F_N = \frac{\mu_0}{4\pi} \frac{q_m}{(r-l)^2} \hat{i} \rightarrow (1)$$

ATTRACTIVE FORCE

$$F_S = -\frac{\mu_0}{4\pi}\frac{q_m}{(r+l)^2}\cdot\hat{i} \longrightarrow (2)$$

TOTAL MAGNETIC FIELD :

$$\vec{B} = \vec{F_N} + \vec{F_S}$$

$$\vec{B} = \left[\left(\frac{\mu_0}{4\pi}\frac{q_m}{(r-l)^2}\cdot\hat{i}\right) + \left(-\frac{\mu_0}{4\pi}\frac{q_m}{(r+l)^2}\cdot\hat{i}\right)\right]$$

$$\vec{B} = \left[\frac{\mu_0}{4\pi}\frac{q_m}{(r-l)^2} - \frac{\mu_0}{4\pi}\frac{q_m}{(r+l)^2}\right]\cdot\hat{i}$$

$$\vec{B} = \left[\frac{\mu_0 q_m}{4\pi}\frac{1}{(r-l)^2} - \frac{\mu_0 q_m}{4\pi}\frac{1}{(r+l)^2}\right]\cdot\hat{i}$$

$$\vec{B} = \frac{\mu_0 q_m}{4\pi}\left[\frac{1}{(r-l)^2} - \frac{1}{(r+l)^2}\right]\cdot\hat{i}$$

$$\vec{B} = \frac{\mu_0 q_m}{4\pi}\left[\frac{(r+l)^2 - (r-l)^2}{(r-l)^2\ (r+l)^2}\right]\cdot\hat{i}$$

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$$(a+b)^2 = a^2 + b^2 + 2ab$$

$$(a-b)^2 = a^2 + b^2 - 2ab$$

$$\vec{B} = \frac{\mu_0 q_m}{4\pi}\left[\frac{(r^2+l^2+2rl)-(r^2+l^2-2rl)}{(r^2-l^2)^2}\right].\hat{i}$$

$$\vec{B} = \frac{\mu_0 q_m}{4\pi}\left[\frac{\cancel{r^2}+\cancel{l^2}+2rl-\cancel{r^2}-\cancel{l^2}+2rl}{(r^2-l^2)^2}\right].\hat{i}$$

$$\vec{B} = \frac{\mu_0 q_m}{4\pi}\left[\frac{2rl+2rl}{(r^2-l^2)^2}\right].\hat{i}$$

l - Neglected

$[r>>l]$ at very small distance

$$\vec{B} = \frac{\mu_0 q_m}{4\pi}\left[\frac{4rl}{(r^2)^2}\right].\hat{i}$$

$$\vec{B} = \frac{\mu_0 q_m}{4\pi}\left[\frac{4rl}{r^4}\right].\hat{i}$$

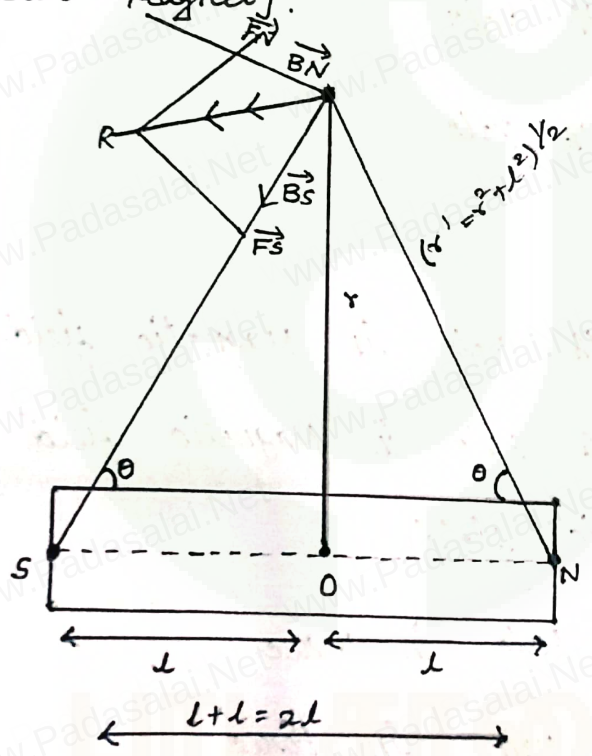
$$\vec{B} = \frac{\mu_0 q_m}{4\pi}\left[\frac{4l}{r^3}\right].\hat{i}$$

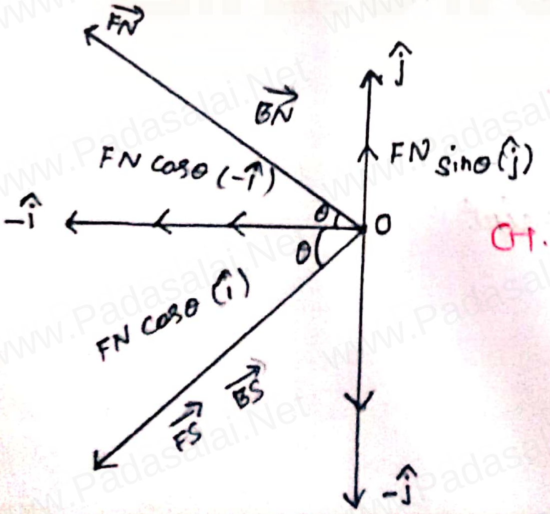
$$\vec{B} = \frac{\mu_0}{4\pi}\left[\frac{q_m \times 4l}{r^3}.\hat{i}\right]$$

$$\hat{i}\,(q_m \times 4l) = 2\,\vec{P_m}$$

$$\boxed{\vec{B} = \frac{\mu_0}{4\pi}\,\frac{2\vec{P_m}}{r^3}}$$

2. Magnetic field at a point along the equcation line due to an magnetic dipole [Bar magnet].





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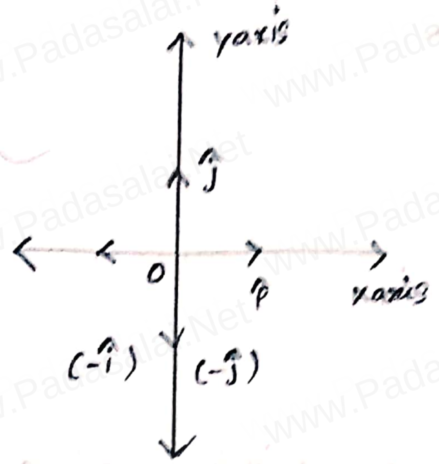

θ = Angle

S = South Pole

N = North Pole

F = Force

Bs = South Pole in Magnetic field

BN = North Pole in Magnetic field

B = Magnetic field

Fs = South Pole in Force

FN = North Pole in Force

c = Free space

O = center of Point

l = length

r = Distance

$$\left.\begin{array}{l} F_N \sin\theta\ (\hat{j}) \\ F_S \sin\theta\ (-\hat{j}) \end{array}\right\} \rightarrow \text{vertical components}$$

$$\left.\begin{array}{l} F_N \cos\theta\ (-\hat{i}) \\ F_N \cos\theta\ (\hat{i}) \end{array}\right\} \rightarrow \text{Horizontal components}$$

$OC = r$

$SO = l$

$ON = l$

$SN = l + l = 2l$

$2d$ = very small distance

REPULSIVE FORCE

$$\vec{F_N} = -F_N \cos\theta\ \hat{i} + F_N \sin\theta\ \hat{j}$$

ATTRACTIVE FORCE

$$\vec{F_S} = -F_S \cos\theta\ \hat{i} - F_S \sin\theta\ \hat{j}$$

Repulsive Force
(Repulsive)

$$F_N = \frac{\mu_0}{4\pi} \frac{q_m}{r^{12}}$$

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Attractive Force

$$F_S = \frac{\mu_0}{4\pi} \frac{q_m}{r'^2}$$

q_m = Magnetic pole strength

$$\vec{F_N} = \frac{\mu_0}{4\pi} \frac{q_m}{r'^2}$$

$$\boxed{r' = r^2 + l^2}$$

$$\vec{F_N} = \frac{\mu_0}{4\pi} \frac{q_m}{(r^2+l^2)^{1/\cancel{2} \times \cancel{2}}} \rightarrow (1)$$

$$\vec{F_S} = \frac{\mu_0}{4\pi} \frac{q_m}{r'^2}$$

$$\vec{F_S} = \frac{\mu_0}{4\pi} \frac{q_m}{(r^2+l^2)^{1/\cancel{2} \times \cancel{2}}} \rightarrow (2)$$

$\mu_0 \rightarrow$ Permeability of free space

$\mu_0 \rightarrow 4\pi \times 10^{-7}$ H/m

$\mu_0 \rightarrow 4 \times 3.14 \times 10^{-7}$ H/m

TOTAL MAGNETIC FIELD

$$\vec{B} = -(\vec{F_N} + \vec{F_S})\cos\theta\,\hat{i}$$

$$\vec{B} = -\left(\frac{\mu_0}{4\pi}\frac{q_m}{(r^2+l^2)}\cos\theta\,\hat{i}\right)$$

$$\vec{B} = -\frac{\mu_0}{4\pi}\frac{q_m}{(r^2+l^2)} \times \cos\theta\,\hat{i}$$

$$\boxed{\cos\theta = \frac{l}{\sqrt{r^2+l^2}}}$$

$$\vec{B} = -\frac{\mu_0}{4\pi}\frac{q_m}{(r^2+l^2)} \times \frac{l}{\sqrt{r^2+l^2}} \times \hat{i}$$

$$\vec{B} = -\frac{\mu_0}{4\pi}\frac{q_m}{(r^2+l^2)} \times \frac{l}{\sqrt{r^2+l^2}} \times \hat{i}$$

$$\vec{B} = -\frac{\mu_0}{4\pi}\frac{q_m}{(r^2+l^2)} \times \frac{l}{(r^2+l^2)^{1/2}}\cdot\hat{i}$$

$$\vec{B} = -\frac{\mu_0}{4\pi}\frac{q_m \times l}{(r^2+l^2)^{1/2+1}}\cdot\hat{i}$$

$$\vec{B} = -\frac{\mu_0}{4\pi}\frac{\vec{P_m}}{(r^2+l^2)^{3/2}}\cdot\hat{i}$$

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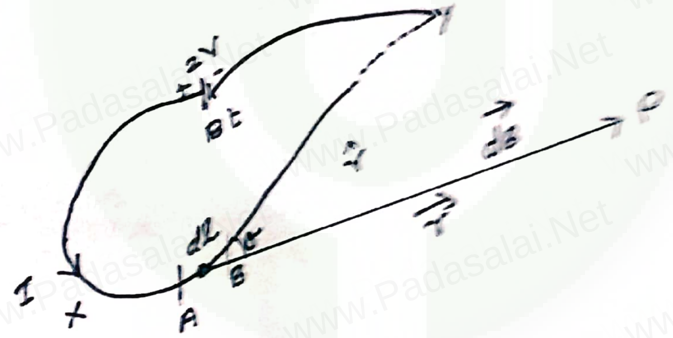
$l \to$ Neglected

$$\vec{B} = \frac{-\mu_0}{4\pi} \frac{\vec{P_m}}{(r^2)^{3/2}}$$

$$\boxed{\vec{B} = -\frac{\mu_0}{4\pi} \frac{\vec{P_m}}{r^3}}$$

$\vec{P_m}$ = Magnetic Dipole Moment

3. BIOT SAVART LAW



Biot savart law

$$\boxed{dB \propto \frac{Idl}{r^2} \sin\theta}$$

xy => Conductor

I => current

θ => Angle

$\vec{dB}$ => Magnitude of Magnetic field

B => Magnetic field

r => Distance

$\hat{r}$ => unit vector

dl => small element length

V => Voltage (or) Potential Difference

$$\boxed{dB \propto \frac{Idl}{r^2} \sin\theta}$$

i) Directly Proportional strength of the current (I).

ii) Directly Proportional small element length (dl).

iii) Directly Proportional sine of a angle at a Point P ($\sin\theta$)

iv) Directly Proportional Inverse square of distance at a point P ($1/r^2$)

BIOT SAVART LAW

$$dB \propto \frac{Idl}{r^2} \sin\theta$$

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$$dB = K \frac{I dl \sin\theta}{r^2}$$

K = constant of proportionality

$$dB = K \frac{I dl}{r^2} \sin\theta$$

$$K = \frac{\mu_0}{4\pi}$$

$\mu_0 \rightarrow$ Permeability of free space

$\mu_0 \Rightarrow 4\pi \times 10^{-7}$ H/m

H ⇒ henry

M ⇒ meter

$$K = \frac{\cancel{4\pi} \times 10^{-7}}{\cancel{4\pi}}$$

$$= 10^{-7} \text{ H/m}$$

$$dB = K \frac{I dl \sin\theta}{r^2}$$

$$dB = \frac{\mu_0}{4\pi} \frac{I dl \sin\theta}{r^2}$$

VECTOR NOTATION :-

$$\vec{dB} = \frac{\mu_0}{4\pi} \frac{I dl \times \hat{r}}{r^2}$$

$\wedge \rightarrow$ unit vector

Magnetic field

$$B = \int \vec{dB}$$

$$B = \int \frac{\mu_0}{4\pi} \frac{I dl \times \hat{r}}{r^2}$$

$$B = \frac{\mu_0}{4\pi} \int \frac{I dl \times \hat{r}}{r^2}$$

$$\boxed{B = \frac{\mu_0 I}{4\pi} \int \frac{dl \times \hat{r}}{r^2}}$$

SPECIAL CASE

Biot savart law

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$$dB = \frac{\mu_0}{4\pi} \frac{I dl \sin\theta}{r^2}$$

i) If the Point P lies between $\boxed{\theta = 0°}$

$$dB = \frac{\mu_0}{4\pi} \frac{I dl \,(\sin(0°))}{r^2}$$

$\sin(0^\circ)=0$

$$dB = \frac{\mu_0}{4\pi} \frac{I\,dl\,(0)}{r^2}$$

$$dB = \frac{\mu_0}{4\pi}(0)$$

$$\boxed{dB=0}$$

This current is zero.

<u>SPECIAL CASE</u> :-

PERPENDICULAR

$$\boxed{\theta=90^\circ}$$

$$dB = \frac{\mu_0}{4\pi} \frac{I\,dl\,\sin\theta}{r^2}$$

$$\boxed{\sin(90^\circ)=1}$$

$$dB = \frac{\mu_0}{4\pi} \frac{I\,dl\,(1)}{r^2}$$

$$dB = \frac{\mu_0}{4\pi} \frac{I\,dl}{r^2}$$

vector notation

$$\vec{dB} = \frac{\mu_0}{4\pi} \frac{I dl \times \hat{r}}{r^2}$$

$$\vec{dB} = \frac{\mu_0}{4\pi} \frac{I dl}{r^2} \times \hat{n}$$

$$\boxed{\vec{dB} = \frac{I dl}{r^2} \times \hat{n}}$$

SIMILARITIES COULOMB'S LAW AND BIOT SAVART LAW :-

$$\boxed{B \propto q}$$

$$\boxed{E \propto I dl}$$

$\mu_0 \rightarrow$ Permeability of free space

$\mu_0 \rightarrow 4\pi \times 10^{-7}$ H/m

$\mu_0 \rightarrow 4\pi \times 3.14 \times 10^{-7}$ H/m

$$K = \frac{\mu_0}{4\pi}$$

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$$\boxed{K = 1}$$

$\mu_r \rightarrow$ Relative Permeability

$\mu_0 \rightarrow$ Permeability of free space

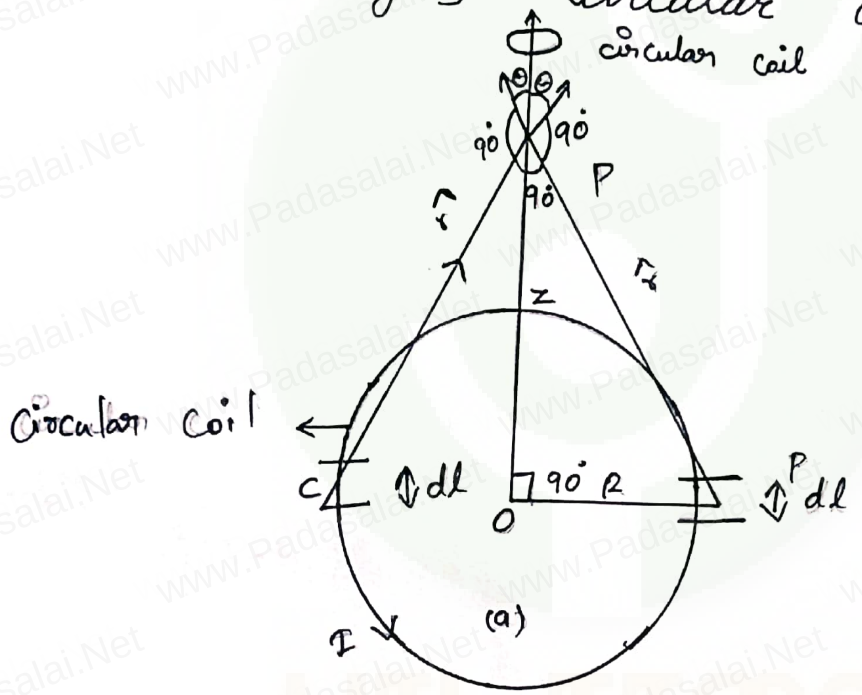
μ ⇒ Permeability of medium

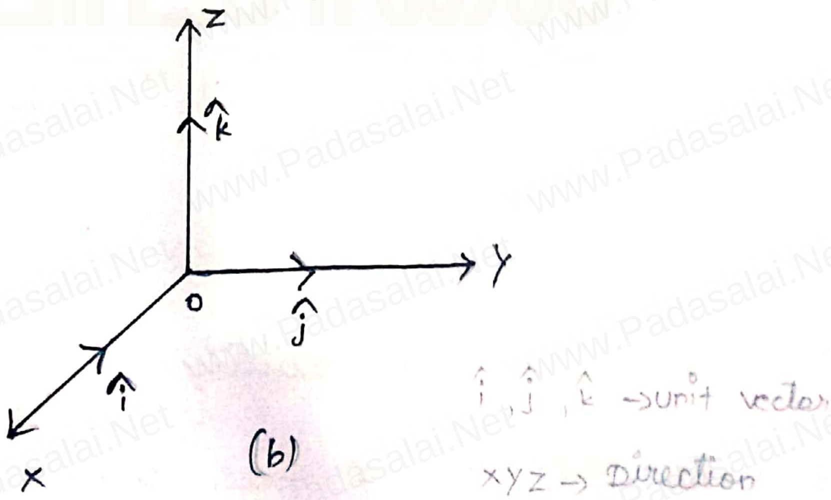
UNIT

Magnetic Induction

Tesla (or) weber m^{-2}

4. Magnetic field produced along axis current carrying circular coil.





$dL \rightarrow$ small element of length

$\left.\begin{array}{l} dB\cos\theta \\ dB\cos\theta \end{array}\right\} \Rightarrow$ Vertical component

$\left.\begin{array}{l} dB\sin\theta \\ dB\sin\theta \end{array}\right\} \Rightarrow$ Horizontal component

$O \rightarrow$ center of Point

$I \rightarrow$ current

$B \rightarrow$ Magnetic field

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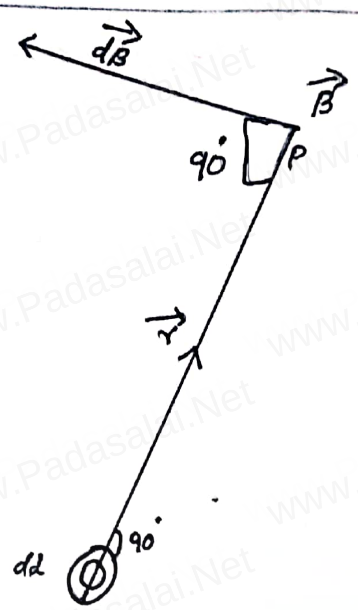
$\theta \rightarrow$ Angle

$dB \rightarrow$ Magnitude of Magnetic field



(d)

using Biot savart law

$\boxed{\theta = 90^\circ}$

$$\vec{dB} = \frac{\mu_0}{4\pi} \frac{I dl}{r^2} \sin\theta$$

$\boxed{\theta = 90^\circ}$

$$\vec{dB} = \frac{\mu_0}{4\pi} \frac{I dl}{r^2} \sin(90^\circ)$$

$$\sin(90^\circ) = 1$$

$$\vec{dB} = \frac{\mu_0}{4\pi} \frac{I dl}{r^2} (1)$$

$$\vec{dB} = \frac{\mu_0}{4\pi} \frac{I dl}{r^2}$$

$\mu_0 \to$ permeability of free space

$\mu_0 \to 4\pi \times 10^{-7}$ H/m

$\mu_0 \to 4 \times 3.14 \times 10^{-7}$ H/m

Vector notation

$$\boxed{\vec{dB} = \frac{\mu_0}{4\pi} \frac{I dl}{r^2} \times \hat{r}}$$

Total magnetic field

$$B = \int \vec{dB} \cdot \cos\theta \cdot \hat{k}$$

$$B = \int \frac{\mu_0}{4\pi} \frac{I dl}{r^2} \cos\theta \cdot \hat{k}$$

$$B = \frac{\mu_0 I}{4\pi} \int \frac{dl}{r^2} \cos\theta \cdot \hat{k}$$

$$B = \frac{\mu_0 I}{4\pi} \int \frac{1}{r^2} dl \cos\theta \cdot \hat{k}$$

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$$B = \frac{\mu_0 I}{4\pi} \frac{1}{r^2} \cos\theta \, \hat{k} \int dl$$

$$\boxed{r^2 = R^2 + z^2}$$

$$B = \frac{\mu_0 I}{4\pi} \frac{1}{(R^2+z^2)} \cos\theta \, \hat{k} \int dl$$

$$\boxed{\cos\theta = \frac{R}{(R^2+z^2)^{1/2}}}$$

$$B = \frac{\mu_0 I}{4\pi} \frac{1}{(R^2+z^2)} \cos\theta \, \hat{k} \int dl$$

$$B = \frac{\mu_0 I}{4\pi} \frac{1}{(R^2+z^2)} \frac{R}{(R^2+z^2)} \hat{k} \int dl$$

$$B = \frac{\mu_0 I}{4\pi} \frac{R}{(R^2+z^2)^{1+1/2}} \hat{k} \int dl$$

$$B = \frac{\mu_0 I}{4\pi} \frac{R}{(R^2+z^2)^{3/2}} \hat{k} \int dl$$

$$B = \frac{\mu_0}{4\pi} \frac{R}{(R^2+z^2)^{3/2}} \times 2\pi R . \hat{k}$$

$$\boxed{\int dl = 2\pi R}$$

$$B = \frac{\mu_0 I}{4\pi} \frac{2\pi R . (R)}{(R^2+z^2)^{3/2}} . \hat{k}$$

$$B = \frac{\mu_0 I}{\cancel{4\pi}} \frac{\cancel{2\pi} R^2}{(R^2+z^2)^{3/2}} . \hat{k}$$

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$$\boxed{B = \frac{\mu_0 I}{2\pi} \frac{R^2}{(R^2+z^2)^{3/2}} . \hat{k}}$$