CHAPTER 22

1. $\vec{F} = q\,\vec{v} \times \vec{B}$

(a) $\vec{v} \times \vec{B}$ points up $\uparrow$, $q > 0$, so $\vec{F}$ points $\underline{\uparrow}$

(b) $\vec{v} \times \vec{B}$ points in $\otimes$, $q < 0$, so $\vec{F}$ points out
<u>out of the page.</u>

(c) $\vec{v} \times \vec{B} = 0$ so $\vec{F} = 0$ (<u>no deflection</u>)

(d) $\vec{v} \times \vec{B}$ points in $\otimes$, $q > 0$, so $\vec{F}$ points
<u>into the page</u> $\otimes$.

2. At the equator the magnetic field points horizontally north.

(a) $\vec{v} \times \vec{B}$ points east, so $\vec{F}$ points <u>west</u>
(electron charge is negative).

(b) $\vec{v} \times \vec{B} = 0$ so $\vec{F} = 0$ (<u>no deflection</u>)

(c) $\vec{v} \times \vec{B}$ points down so $\vec{F}$ points <u>up</u>.

(d) $\vec{v} \times \vec{B}$ points up, so $\vec{F}$ points <u>down</u>

4. $K.E. = 2400V \cdot e = 2400 eV = 3.84 \cdot 10^{-16} J$

$K.E = \frac{m_e v^2}{2}$

$v = \sqrt{\frac{2K.E.}{m_e}} = 2.9 \cdot 10^7 \, m/s$

$\vec{F} = q\vec{v} \times \vec{B}$

$F = |q| v B |\sin\theta|$

(a) $F = F_{max}$ when $|\sin\theta| = 1$

$F_{max} = |q| v B = e v B = \underline{7.9 \cdot 10^{-12} N}$

(b) $F = F_{min}$ when $\sin\theta = 0$

$F_{min} = \underline{0}$

5. $B = 50.0 \mu T = 50 \cdot 10^{-6} T$ (north)

$E = 100 \, N/C$ (down)

$v = 6 \cdot 10^6 \, m/s$ (east)

$F_g = mg = \underline{8.93 \cdot 10^{-30} N, \text{ down}}$

$F_E = eE = \underline{1.6 \cdot 10^{-17} N, \text{ up}}$ (since electron charge is negative)

$\vec{F_B} = q\vec{v} \times \vec{B}$

$\theta = 90°$, $\vec{v} \times \vec{B}$ points up, so $\vec{F_B}$ points down

$F_B = evB = \underline{4.8 \cdot 10^{-17}\,N,\ down}$

62. $\vec{v} \times \vec{B}$ points up, so positive charges are pushed up and negatives down under the magnetic force. However the charges cannot escape the vessel, so the overall force on them must be 0, the magnetic force must be exactly cancelled by the electric force created by the separation of charges. So the electric field points down (from positive to negative charges) and for a given charge q

$$qvB = qE$$

$$E = vB$$

also $\Delta V = E \cdot d \Rightarrow E = \frac{\Delta V}{d}$

$$\frac{\Delta V}{d} = vB$$

(a) $v = \frac{\Delta V}{dB} = \frac{160 \cdot 10^{-6}\,V}{3 \cdot 10^{-3}\,m \cdot 0{,}04\,T} = \underline{1.33\,m/s}$

(b) The sign of emf does not depend on

whether the mobile ions are predominantly positively or negatively charged. The positive charges are pushed up and negatives down, but even if there are no positive charges (free), the motion of negative charges down gives electrode A positive charge and higher potential.

9 $K.E. = 10\ MeV = 10 \cdot 10^6\ eV$

$R = 5.8 \cdot 10^{10}\ m$

$K.E. = \frac{mv^2}{2} \Rightarrow mv^2 = 2K.E.,\ v = \sqrt{\frac{2K.E.}{m}}$

$F = evB$ and gives centripetal acceleration:

$F = ma = m\frac{v^2}{R} = \frac{2K.E.}{R}$

$evB = \frac{2K.E.}{R}$

$B = \frac{2K.E.}{ReV} = \frac{2K.E.}{Re\sqrt{\frac{2K.E.}{m}}} = \frac{\sqrt{2K.E.m}}{Re}$

$B = \frac{\sqrt{2 \cdot 10^7 \cdot 1.6 \cdot 10^{-19} J \cdot 1.67 \cdot 10^{-27} kg}}{5.8 \cdot 10^{10} m \cdot 1.6 \cdot 10^{-19} C} = \underline{7.88 \cdot 10^{-12}\ T}$

11. $E = 2500\ V/m$

$B = 0{,}035\ T$

$m = 2{,}18 \cdot 10^{-26}\ kg$

In the velocity selector:

$$qVB = qE$$

$$V = \frac{E}{B} = 7{,}14 \cdot 10^{4}\ m/s$$

$$F_B = ma$$

$$qVB = m\frac{V^2}{R}$$

$$R = \frac{mV}{qB} = \frac{mV}{eB} = \underline{0{,}278\ m}$$

60. $B = 2.4\ T$

$$F = ma$$

$$qVB = m\frac{V^2}{R}$$

$$qB = m\frac{V}{R} = m\omega \qquad \left(\omega = \frac{V}{R}\right)$$

$$\omega = \frac{qB}{m}$$

$$\omega_1 - \omega_2 = \frac{qB}{m_1} - \frac{qB}{m_2}, \qquad q = e$$

$$m_1 = 12u = 12 \cdot 1.66 \cdot 10^{-27}\ kg = 1{,}99 \cdot 10^{-26}\ kg$$

$$m_2 = 14u = 2{,}32 \cdot 10^{-26}\ kg$$

$\omega_1 - \omega_2 = 2.75 \cdot 10^6 \ rad/s$

61. $B = 0{,}15 \ T$

$v = 5 \cdot 10^6 \ m/s$

$\theta = 85°$

$V_x = v\cos\theta = 4{,}36 \cdot 10^5 \ m/s$

$F = q v B \sin\theta = ma$

$q = e = 1.6 \cdot 10^{-19} C$

$m = m_e = 9.11 \cdot 10^{-31} kg$

$qvB\sin\theta = m\frac{v^2}{r}$

(b) $r = \frac{mV}{qB\sin\theta} = 1{,}9 \cdot 10^{-4} m$

(a) $T = \frac{2\pi r}{V\sin\theta} = 2{,}40 \cdot 10^{-10} s$

$p = T V_x = 1{,}04 \cdot 10^{-4} m$

15 $\vec{l} = 0{,}75 \ m \cdot \hat{i}$

$I = 2.40 A$

$\vec{B} = 1{,}6 \ T \cdot \hat{k}$

$\vec{F} = I \cdot \vec{l} \times \vec{B} = -2.88 \hat{j} \ N$

16 $l = 2.8\,m$

$I = 5\,A$

$B = 0.39\,T$

$F = lIB\sin\theta = 5.46\,N \cdot \sin\theta$

(a) $\theta = 60°$, $\sin\theta = \frac{\sqrt{3}}{2}$

$F = \underline{4.73\,N}$

(b) $\theta = 90°$, $\sin\theta = 1$

$F = \underline{5.46\,N}$

(c) $\theta = 120°$, $\sin\theta = \frac{\sqrt{3}}{2}$

$F = \underline{4.73\,N}$

18 $\underline{\vec{F}_{ab} = 0}$ since $\vec{l}_{ab} \parallel \vec{B}$

$\vec{F}_{bc} = I\,\vec{l}_{bc} \times \vec{B} = I\,l\,\hat{k} \times B\,\hat{j} = \underline{-0.04\,\hat{i}\,N}$

$(l = 0.4\,m,\quad B = 0.02\,T,\quad I = 5\,A)$

$\vec{l}_{cd} = l(-\hat{i} + \hat{j})$

$\vec{F}_{cd} = IlB\,(-\hat{i} + \hat{j}) \times \hat{i} = -IlB\,\hat{i} \times \hat{i} = -IlB\,\hat{k} =$

$= \underline{-0.04\,\hat{k}\,N}$

$\vec{l}_{da} = l(\hat{i} - \hat{k})$

$\vec{F}_{da} = IlB(\hat{i} - \hat{k}) \times \hat{j} = IlB(\hat{k} + \hat{i}) =$

$= \underline{0{,}04\ N\ (\hat{k} + \hat{i})}$

19. $I = 17\ mA = 17 \cdot 10^{-3}\ A$

$2\pi r = 2m$

$B = 0.8T$

(a) $r = \frac{2m}{2\pi} = 0{,}318\ m$

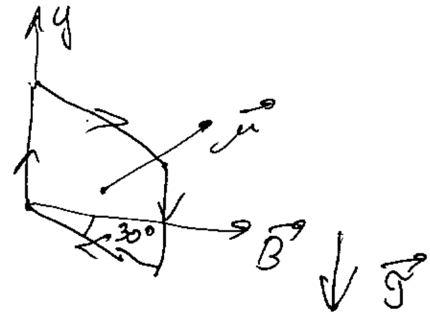
$\mu = I \cdot A = I \pi r^2 = \underline{5{,}41 \cdot 10^{-3}\ A \cdot m^2}$

(b) $\vec{\tau} = \vec{\mu} \times \vec{B} = \mu B \sin\theta$

$\theta = 90° \Rightarrow \sin\theta = 1$ ($\vec{\mu}$ is perpendicular to the plane of the loop)

$\tau = \mu B = \underline{4{,}33 \cdot 10^{-3}\ N \cdot m}$

21. $N = 100$
$a = 0{,}4\ m$
$b = 0{,}3\ m$
$\theta = 30°$
$B = 0.8\ T$
$I = 1.2\ A$



$\mu = NIA = NIab$

The angle between $\vec{\mu}$ and $\vec{B}$ is $60°$, so

$\vec{\tau} = \vec{\mu} \times \vec{B}$

$\tau = \mu B \sin 60° = NIab\,B \sin 60° = \underline{9.98\ N\cdot m}$

τ points down, so the loop will rotate in the clockwise direction when looking down along the y-axis.

22 $N = 80$

$a = 0.025\,m$

$b = 0.04\,m$

$B = 0.8\,T$, $I = 10\,mA = 10^{-2}A$

$f = 3600$ rev/min $= 60$ rev/s

(a) $\vec{\tau} = \vec{\mu} \times \vec{B}$

$\mu = NIA = NIab$

$\tau = \mu B |\sin\theta|$

$\tau = \tau_{max}$ when $|\sin\theta| = 1$

$\tau_{max} = \mu B = NIab\,B = \underline{6.4 \cdot 10^{-4}\ N\cdot m}$

(b) $P = \tau \cdot \omega$

$$P_{max} = \tau_{max} \cdot \omega = \tau_{max} \cdot 2\pi f = \underline{0.241\,W}$$

(c) $P = \tau \cdot \omega = \tau_{max} \cdot |\sin\theta| \cdot \omega = P_{max} \cdot |\sin\theta|$

$$dW = P\,dt$$

$$W = \int_0^T P_{max} |\sin\theta|\, dt$$

$$\omega = \frac{d\theta}{dt}$$

$$W = \int_0^{2\pi} P_{max} |\sin\theta| \frac{d\theta}{\omega} = \int_0^{2\pi} \tau_{max} |\sin\theta|\, d\theta =$$

$$= 2\tau_{max} \int_0^{\pi} \sin\theta\, d\theta = 2\tau_{max} \left(-\cos\theta \Big|_0^{\pi}\right) =$$

$$= 4\tau_{max} = \underline{2.56 \cdot 10^{-3}\,J}$$

(d) $P_{avg} = \frac{W}{T} = Wf = \underline{0.154\,W}$

23 $v = 2.19 \cdot 10^{6}\,m/s$

$r = 5.29 \cdot 10^{-11}\,m$

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I\, d\vec{s} \times \hat{r}}{r^2}$$

$$B = \frac{\mu_0}{4\pi} \frac{I \cdot 2\pi r}{r^2} = \frac{\mu_0 I}{2r}$$

$$I = \frac{e}{T} = \frac{e}{2\pi r / v} = \frac{ev}{2\pi r}$$

$$B = \frac{\mu_0}{2r} \cdot \frac{ev}{2\pi r} = \frac{\mu_0 e v}{4\pi r^2} = \underline{12.5\ T}$$

25 $I = 1 \cdot 10^4\ A$

$r = 100 m$

$$B = \frac{\mu_0 I}{2\pi r} = \underline{2 \cdot 10^{-5}\ T}$$

(we use the equation for a long straight wire for the bolt)

26 $r = 100 cm = 1 m$

$I = 1 A$

$$B = \frac{\mu_0 I}{2\pi r} = \underline{2 \cdot 10^{-7}\ T}$$

27

We have to add magnetic fields created by a long straight wire and a loop at the center of the loop, Both point <u>into the page</u>.

$$B_{straight} = \frac{\mu_0 I}{2\pi R}$$

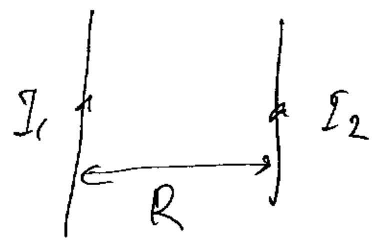
$$B_{loop} = \frac{\mu_0}{4\pi} \cdot \frac{I \cdot 2\pi R}{R^2} = \frac{\mu_0 I}{2R}$$

$$B = B_{straight} + B_{loop} = \underline{\frac{\mu_0 I}{2R}\left(\frac{1}{\pi} + 1\right)}$$

3) $I_1 = 5\,A$

$I_2 = 8\,A$

$R = 10\,cm = 0{,}1\,m$



(a) $B_1 = \frac{\mu_0 I_1}{2\pi R} = \underline{10^{-5}\,T \text{ (into the page)}}$

(b) $l = 1\,m$

$\vec{F}_2 = I_2\, \vec{l} \times \vec{B}_1$

$F_2 = I_2\, l\, B_1 = \underline{8 \cdot 10^{-5}\,N \text{ (to the left)}}$

(c) $B_2 = \frac{\mu_0 I_2}{2\pi R} = \underline{1{,}6 \cdot 10^{-5}\,T \text{ (out of the page)}}$

(d) $l = 1\,m$

$\vec{F}_1 = I_1\, \vec{l} \times \vec{B}_2$

$F_1 = I_1\, l\, B_2 = \underline{8 \cdot 10^{-5}\,N \text{ (to the right)}}$

(the wires attract each other, Newton's 3rd law is satisfied)

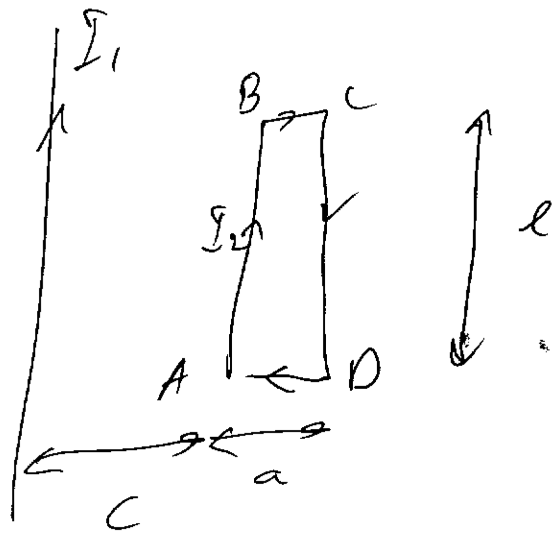
35 $I_1 = 5\,A$

$I_2 = 10\,A$

$c = 0{,}1\,m$

$a = 0{,}15\,m$

$l = 0{,}45\,m$



The field created by I_1 at the location of the loop points into the page and is given by

$$B = \frac{\mu_0 I_1}{2\pi R}$$

so the force on BC points up, on AD points down, they are equal in magnitude since they carry the same current and are at the same distance from I_1, hence they cancel each other.

The force on AB points left and is equal to

$$F_{AB} = I_2 \cdot l \cdot B_{AB} = I_2 l \frac{\mu_0 I_1}{2\pi c}$$

The force on CD points right and is equal to

$$F_{CD} = I_2 \cdot \ell B_{CD} = I_2 \ell \frac{\mu_0 I_1}{2\pi(c+a)}$$

so overall

$$\hat{F} = F_{AB} - F_{CD} = \frac{\mu_0 I_1 I_2 \ell}{2\pi}\left(\frac{1}{c} - \frac{1}{c+a}\right) = \underline{2.7 \cdot 10^{-5} N}$$

<u>to the left</u>

<u>4)</u> $N = 900$

$R_{in} = 0.7 m$

$R_{out} = 1.3 m$

$I = 14 kA = 14 \cdot 10^3 A$

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 N I$$

$$B \cdot 2\pi R = \mu_0 N I$$

<u>(a)</u> $B_{in} \cdot 2\pi R_{in} = \mu_0 N I$

$$B_{in} = \frac{\mu_0 N I}{2\pi R_{in}} = \underline{3.6 T}$$

<u>(B)</u> $B_{out} \cdot 2\pi R_{out} = \mu_0 N I$

$$B_{out} = \frac{\mu_0 N I}{2\pi R_{out}} = \underline{1.94 T}$$

43 $B_{surface} = 0{,}1\,T$

$d = 2\,mm = 2\cdot 10^{-3}\,m$

$r = \frac{d}{2} = 10^{-3}\,m$

$$B_{surface} = \frac{\mu_0 I}{2\pi r}$$

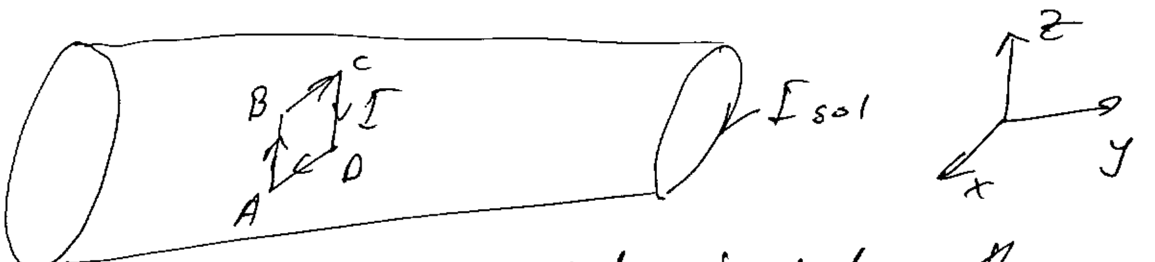
$$I = \frac{2\pi r\, B_{surface}}{\mu_0} = \underline{500\,A}$$

44 $I = 0{,}2\,A$

$a = 2\,cm = 0{,}02\,m$

$n = 30\,turns/cm = 3\cdot 10^3\,turns/m$

$I_{sol} = 15\,A$



The magnetic field inside the solenoid points to the left and is equal to

$B = \mu_0 n I_{sol}$

i.e. $\vec{B} = -\mu_0 n I_{sol}\,\hat{j}$

$\vec{l}_{AB} = a\,\hat{k}$

$\vec{F}_{AB} = I\,\vec{l}_{AB}\times\vec{B} = -Ia\mu_0 n I_{sol}(\hat{k}\times\hat{j}) = Ia\mu_0 n I_{sol}\,\hat{i}$

$\vec{F}_{AB} = 2.26 \cdot 10^{-4}\, N \cdot \hat{i}$ (i.e. out of the page)

$\vec{l}_{BC} = -a\hat{i}$

$\vec{F}_{BC} = I a \mu_0 n I_{sol} (\hat{i} \times \hat{j}) = I a \mu_0 n I_{sol} \hat{k}$

$\vec{F}_{BC} = 2.26 \cdot 10^{-4}\, N \cdot \hat{k}$ (i.e. up)

$\vec{l}_{CD} = -a\hat{k}$

$\vec{F}_{CD} = I a \mu_0 n I_{sol} (\hat{k} \times \hat{j}) = -I a \mu_0 n I_{sol} \hat{i}$

$\vec{F}_{CD} = -2.26 \cdot 10^{-4}\, N \hat{i}$ (i.e. into the page)

$\vec{l}_{DA} = a\hat{i}$

$\vec{F}_{DA} = -I a \mu_0 n I_{sol} (\hat{i} \times \hat{j}) = -I a \mu_0 n I_{sol} \hat{k}$

$\vec{F}_{DA} = -2.26 \cdot 10^{-4}\, N \hat{k}$ (i.e. down)

All the forces are parallel to the plane of the loop (they all point away from its center) so the net torque is 0.
Another way to see that is that $\vec{\mu} \parallel \vec{B}$
so $\vec{\tau} = \vec{\mu} \times \vec{B} = 0$.

45 $N = 1000$

$\ell = 0.4\,m$

$B = 10^{-4}\,T$

$n = \dfrac{N}{\ell} = 2500$ turns/m

$B = \mu_0 I n$

$I = \dfrac{B}{\mu_0 n} = \underline{3.18 \cdot 10^{-2}\,A}$

48 $R = 5.29 \cdot 10^{-11}\,m$

$v = 2.19 \cdot 10^{6}\,m/s$

(a) $I = \dfrac{e}{T} = \dfrac{e}{2\pi R/v} = \dfrac{ev}{2\pi R}$

$\mu = I A = I \pi R^2 = \cancel{\pi} \dfrac{ev}{2\cancel{\pi}\cancel{R}} \cdot R^{\cancel{2}} = \dfrac{evR}{2}$

$\underline{\mu = 9.27 \cdot 10^{-24}\,A \cdot m^2}$

(b) For a positive charge $\vec{\mu}$ would point upward by the right hand rule, but the electron is negatively charged, so $\vec{\mu}$ points <u>downward</u>.