PhyzExamples: Adv. Electromagnetism

Physical Quantities • Symbols • Units • Brief Definitions

Magnetic Field • B • tesla: T • The magnetic disturbance in a region of space caused by electric current; the quantitative measure of that disturbance. Magnetic flux density.
Permeability Constant • $\mu = 4\pi \times 10^{-7}$ T·m/A.
Magnetic Force • F • newton: N • The interaction between magnetic poles or between moving charged particles or between current-carrying wires or between any combination of the aforementioned.
Magnetic Flux • Φ • weber (*VAY bur*): Wb or tesla-meter squared: $T \cdot m^2$ • The product of magnetic field and area of an enclosed region.

Equations

$B = \mu/2\pi \cdot I/d$ • *magnetic field = (permeability constant / two · pi) · current through a long, thin wire / distance from the wire.*
$F = ILB$ • *magnetic force = current in a wire · length of wire in magnetic field · magnetic field. Caution: this equation assumes* $\mathbf{L} \perp \mathbf{B}$. *Multiply by the sine of the angle between them if not.*
$F = qvB$ • *magnetic force =charge on a particle · speed of the particle · magnetic field. Caution: this equation assumes* $\mathbf{v} \perp \mathbf{B}$. *Multiply by the sine of the angle between them if not.*
$\mathcal{E} = BLv$ • *induced (motional) electromotive force = magnetic field · length of wire immersed in the field · speed of wire through the field. Caution: this equation assumes* $\mathbf{B} \perp \mathbf{L} \perp \mathbf{v}$.
$\Phi = BA$ • *magnetic flux in an enclosed area = magnetic field in an enclosed area · area enclosed.*
$\mathcal{E} = N\Delta\Phi/t$ • Faraday's Law • *electromotive force induced in a loop or loops = number of loops · change in magnetic flux / time interval over which the change in flux occurred.*

Smooth Operations Examples

1. How strong is the magnetic field 3 cm from a wire carrying 4 A of current?

1. $d = 0.03$ m $I = 4$A $B = ?$

$B = \mu I/2\pi d$

$B = (4\pi \times 10^{-7}$ T/A·m · 4 A)/(2π · 0.03 m)
<u>$B = 2.7\times10^{-5}$ T (=27 μT)</u>

2. Ten centimeters of a wire are exposed to a 6 mT magnetic field directed perpendicular to the wire. How much current must be passed through the wire so that it experiences 2.5 mN of magnetic force?

2. $L = 0.10$ m $B = 6 \times 10^{-3}$ T $F = 0.0025$ N
$I=?$
$F = ILB$
$I = F/LB$
$I = 0.0025$ N / 0.10 m · 6×10^{-3} T
<u>I = 4.2 A</u>

3. At what speed will an electron passing perpendicularly through a 100 T magnetic field experience a magnetic force of 3.2 nN?

3. $q=1.6 \times 10^{-19}$ C $B = 100$ T $F = 3.2\times10^{-9}$ N
$F = qvB$
$v = F/qB$
$v = 3.2\times10^{-9}$ N / 1.6×10^{-19} C · 100 T
<u>$v = 2.0\times10^{8}$ m/s</u> (a speed over 3×10^8 m/s is illegal!)

4. What is the minimum speed of a 12 m wire moving through a 30 μT magnetic field if there is a potential difference of 0.04 V across its length?

4. $L = 12$ m $B = 30 \times 10^{-6}$ T $\mathcal{E} = 0.04$ V $v = ?$
$\mathcal{E} = BLv$
$v = \mathcal{E}/BL$
$v = 0.04$ V / 30×10^{-6} T · 12 m
<u>v = 110 m/s</u>

5. What is the magnetic flux through a circular loop of wire with a radius of 5 mm in a magnetic field of 0.02 T?

5. $r = 0.005$ m $B = 0.02$ T $\Phi = ?$

$\Phi = BA = B \cdot \pi r^2$

$\Phi = 0.02$ T · π · $(0.005$ m$)^2$
<u>$\Phi = 1.6 \times 10^{-6}$ Wb</u>

6. A loop of wire in a magnetic field rotates in such a way that the flux through it changes from 12 Wb to 0 in 0.25 s (then from 0 to 12 Wb in 0.25 s as it continues to rotate). How much emf is generated in the loop?

6. $N = 1 \quad \Delta\Phi = 12$ Wb $\quad t = 0.25$ s $\quad \mathcal{E} = ?$

$\mathcal{E} = N\Delta\Phi/t$

$\mathcal{E} = 1 \cdot 12$ Wb / 0.25 s

$\underline{\mathcal{E} = 48 \text{ V}}$

7. At what rate should the magnetic field through a 20 cm^2 loop of wire change so that an electromotive force of 3 V is generated through it?

7. $N = 1 \quad A = 20 / 100^2 = 0.002\ m^2 \quad \mathcal{E} = 3$ V

$\mathcal{E} = N\Delta\Phi/t = NA(\Delta B/t)$

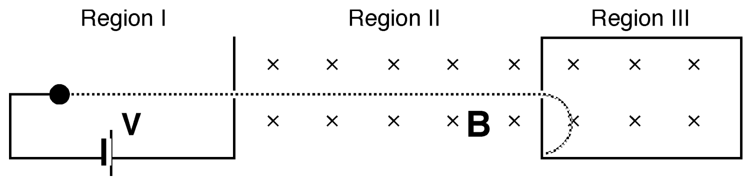
$\Delta B/t = \mathcal{E}/NA$

$\Delta B/t = 3 \text{ V} / 1 \cdot 0.002\ m^2$

$\underline{\Delta B/t = 1500 \text{ T/s}}$

Welcome to the Real World Examples

8. A stream of negatively charged ions is accelerated through an electric potential in region I of the arrangement shown below. When it enters region II, the stream is exposed to electric and magnetic fields at right angles to each other. The ions that enter region III are exposed only to the magnetic field. The potential in region I is V and the magnetic field in regions II and III is B.



a. What is the speed of an ion with a mass *m* and a charge *q* accelerated through region I?

$KE_{gained} = PE_{lost}$

$1/2\ mv^2 = qV$

$v = \sqrt{(2qV/m)}$

b. If an ion of this speed passes undeflected through the crossed electric and magnetic fields in region II, what is the direction and strength of the electric field?

$F_{electric} = F_{magnetic}$

$qE = qvB$

$E = vB$

$E = \sqrt{(2qV/m)} \cdot B$, directed <u>downward</u> (toward bottom of page) to exert <u>upward</u> force on neg. charge

c. Consider an ion that is accelerated through region I and passes undeflected through region II. What will be the radius of curvature of the path it follows when it enters region III?

$F_{centripetal} = F_{magnetic}$

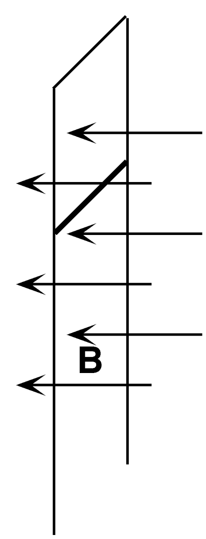
$mv^2/R = qvB$

$R = mv/qB$

$R = m\sqrt{(2qV/m)} / qB$

$R = (1/B)\sqrt{(2mV/q)}$

9. A 10 meter long, 2 millimeter diameter, 0.8 kilogram cylindrical bar falls downward through a 0.36 tesla magnetic field directed to the left. The ends of the bar are connected to rails with negligible resistance that are joined outside the magnetic field so that the arrangement forms a circuit. The bar is made of a material that has a resistivity of 100×10^{-8} ohm-meters.



a. Which way will current flow through the bar as it falls?

Into page (by right hand rule)

b. In what direction will the magnetic field exert a force on the current carried by the bar? Upward

c. What will be the magnetic terminal speed of the falling bar: at what speed will the downward gravitational force be matched by the upward magnetic force? Neglect air resistance

$F_{gravitational} = F_{magnetic}$

$mg = ILB$

$I = \mathcal{E}/R \qquad \mathcal{E} = BLv \qquad R = \rho L/A = 4\rho L/\pi d^2$

$mg = (BLv / 4\rho L/\pi d^2)\ LB$

$v = 4\rho mg / \pi LB^2 d^2 = 4(100 \times 10^{-8}\,\Omega \cdot m)(0.8 kg)(9.8 m/s^2) / \pi\ (10 m)(0.36 T)^2(0.002 m)^2$

$\underline{v = 1.9 \text{ m/s}}$