

Electric Charges and Forces

$$F_{1 \text{ on } 2} = F_{2 \text{ on } 1} = \frac{K|q_1||q_2|}{r^2}$$

$$q = (N_p - N_e)e$$

$$\vec{E} = \vec{F}_{\text{on } q} / q$$

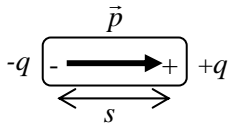
$$\vec{F}_{\text{on } B} = q_B \vec{E}$$

$$\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r} \quad \text{point charge}$$

The Electric Field

$$\vec{E}_{\text{net}} = \sum_i \vec{E}_i$$

Electric dipole:



$$\vec{p} = (qs, \text{ from negative to positive})$$

$$\text{Field on axis } \vec{E} = \frac{1}{4\pi\epsilon_0} \frac{2\vec{p}}{r^3}$$

$$\text{Field in bisecting plane } \vec{E} = -\frac{1}{4\pi\epsilon_0} \frac{\vec{p}}{r^3}$$

Uniform infinite line of charge:

$$\vec{E} = \left(\frac{1}{4\pi\epsilon_0} \frac{2\lambda}{r}, \text{ perpendicular to line} \right)$$

Uniform infinite plane of charge:

$$\vec{E} = \left(\frac{\eta}{2\epsilon_0}, \text{ perpendicular to plane} \right)$$

Uniformly charged sphere:

$$\vec{E} = \frac{Q}{4\pi\epsilon_0 r^2} \hat{r} \quad \text{for } r \geq R$$

Parallel-plate capacitor:

$$\vec{E} = \left(\frac{\eta}{\epsilon_0}, \text{ from positive to negative} \right)$$

$$(E_{\text{ring}})_z = \frac{1}{4\pi\epsilon_0} \frac{zQ}{(z^2 + R^2)^{3/2}}$$

$$(E_{\text{disk}})_z = \frac{\eta}{2\epsilon_0} \left[1 - \frac{z}{\sqrt{z^2 + R^2}} \right]$$

$$\vec{a} = (q/m)\vec{E}$$

$$\tau = pE \sin \theta$$

Gauss's Law

$$\Phi_e = \vec{E} \cdot \vec{A} = EA \cos \theta \quad \text{constant field}$$

$$\Phi_e = \int_{\text{surface}} \vec{E} \cdot d\vec{A}$$

$$\Phi_e = \oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{in}}}{\epsilon_0}$$

\vec{E} at surface of a charged conductor:

$$E_{\text{surface}} = \begin{cases} \frac{\eta}{\epsilon_0} \\ \text{perpendicular to surface} \end{cases}$$

Current and Conductivity

Electron current:

i = rate of electron flow

$$N_e = i\Delta t$$

$$i = nA v_d$$

$$v_d = \frac{e\tau}{m} E$$

Conventional current:

I = rate of charge flow = ei

$$Q = I\Delta t$$

Current density:

$$J = I/A$$

$$J = nev_d = \sigma E$$

$$\sigma = \frac{ne^2\tau}{m} = \frac{1}{\rho}$$

$$\sum I_{\text{in}} = \sum I_{\text{out}}$$

The Electric Potential

$$U_{\text{elect}} = U_0 + qEs \quad (\text{parallel-plate capacitor})$$

$$U_{q_1+q_2} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r} \quad U_{\text{elect}} = \sum_{i < j} \frac{1}{4\pi\epsilon_0} \frac{q_i q_j}{r_{ij}}$$

$$U_{\text{dipole}} = -\vec{p} \cdot \vec{E} = -pE \cos \theta$$

$$U_{q+\text{sources}} = qV \quad V = \frac{U_{q+\text{sources}}}{q}$$

$$V = Es \quad (\text{inside a parallel-plate capacitor})$$

$$\Delta V_{\text{capacitor}} = Ed \quad (\text{parallel plates})$$

$$V = \frac{1}{4\pi\epsilon_0} \frac{q}{r} \quad \text{point charge}$$

$$V = \sum_i \frac{1}{4\pi\epsilon_0} \frac{q_i}{r_i}$$

Potential and Field

$$\Delta V = V(s_f) - V(s_i) = -\int_{s_i}^{s_f} E_s ds$$

= the negative of the area under the E_s graph

$$E_s = -\frac{dV}{ds}$$

$$\Delta V_{\text{loop}} = \sum_i (\Delta V)_i = 0$$

$$\Delta V_{\text{bat}} = \frac{W_{\text{chem}}}{q} = \mathcal{E} \quad (\text{ideal battery})$$

$$E_{\text{wire}} = \frac{\Delta V_{\text{wire}}}{L}$$

$$R = \frac{\rho L}{A} \quad I = \frac{\Delta V_{\text{wire}}}{R}$$

$$C = \frac{Q}{\Delta V_C}$$

$$C = \frac{\epsilon_0 A}{d} \quad (\text{parallel-plate capacitor})$$

$$C_{\text{eq}} = C_1 + C_2 + C_3 + \dots \quad (\text{parallel capacitors})$$

$$C_{\text{eq}} = \left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots \right)^{-1} \quad (\text{series capacitors})$$

$$U_C = \frac{Q^2}{2C} = \frac{1}{2} C (\Delta V_C)^2$$

$$u_E = \frac{\epsilon_0}{2} E^2$$

Fundamentals of Circuits

$$I = \frac{\Delta V}{R}$$

$$\text{junction law: } \sum I_{\text{in}} = \sum I_{\text{out}}$$

$$\text{loop law: } \Delta V_{\text{loop}} = \sum_i (\Delta V)_i = 0$$

$$P_{\text{bat}} = I\mathcal{E}$$

$$P_{\text{R}} = I\Delta V_{\text{R}} = I^2 R = \frac{(\Delta V_{\text{R}})^2}{R}$$

$$R_{\text{eq}} = R_1 + R_2 + R_3 + \dots + R_N \quad (\text{series})$$

$$R_{\text{eq}} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_N} \right)^{-1} \quad (\text{parallel})$$

$$Q = Q_0 e^{-t/\tau} \quad I = I_0 e^{-t/\tau} \quad \tau = RC$$

The Magnetic Field

$$\vec{B} = \frac{\mu_0}{4\pi} \frac{q\vec{v} \times \hat{r}}{r^2} = \left(\frac{\mu_0 |q| v \sin \theta}{4\pi r^2}, \text{RHR} \right)$$

$$\vec{B} = \frac{\mu_0}{4\pi} \frac{I\Delta\vec{s} \times \hat{r}}{r^2} = \left(\frac{\mu_0 I (\Delta s) \sin \theta}{4\pi r^2}, \text{RHR} \right)$$

$$B_{\text{long straight wire}} = \frac{\mu_0 I}{2\pi d} \quad B_{\text{coil center}} = \frac{\mu_0 NI}{2R}$$

$$\vec{\mu} = (AI, \text{from south pole to north pole})$$

$$\vec{B}_{\text{dipole}} = \frac{\mu_0}{4\pi} \frac{2\vec{\mu}}{z^3} \quad (\text{on axis of dipole})$$

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{\text{through}}$$

$$B_{\text{solenoid}} = \frac{\mu_0 NI}{L}$$

$$\vec{F}_{\text{on q}} = q\vec{v} \times \vec{B} = (|q|vB \sin \theta, \text{RHR})$$

$$f_{\text{cyc}} = \frac{qB}{2\pi m} \quad r_{\text{cyc}} = \frac{mv}{qB}$$

$$\vec{F}_{\text{wire}} = I\vec{L} \times \vec{B} = (ILB \sin \theta, \text{RHR})$$

$$F_{\text{parallel wires}} = \frac{\mu_0 I_1 I_2}{2\pi d}$$

$$\vec{\tau} = \vec{\mu} \times \vec{B} = (\mu B \sin \theta, \text{RHR})$$

Electromagnetic Induction

$$\mathcal{E} = v\ell B$$

$$\Phi_{\text{m}} = \vec{A} \cdot \vec{B} = AB \cos \theta \quad (\text{uniform } \vec{B}\text{-field})$$

$$\Phi_{\text{m}} = \int_{\text{area of loop}} \vec{B} \cdot d\vec{A}$$

$$\mathcal{E} = N \left| \frac{d\Phi_{\text{per turn}}}{dt} \right|$$

$$\mathcal{E}_{\text{coil}} = -\omega ABN \sin \omega t$$

$$V_2 = \frac{N_2}{N_1} V_1$$

Electromagnetic Fields and Waves

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{in}}}{\epsilon_0}$$

$$\oint \vec{B} \cdot d\vec{A} = 0$$

$$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_{\text{m}}}{dt}$$

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{\text{through}} + \epsilon_0 \mu_0 \frac{d\Phi_{\text{e}}}{dt}$$

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

$$I_{\text{disp}} = \epsilon_0 \frac{d\Phi_{\text{e}}}{dt}$$

$$v_{\text{em}} = c = 1/\sqrt{\epsilon_0 \mu_0}$$

$$c = \lambda f$$

$$E = cB$$

$$\vec{S} = \frac{1}{\mu_0} (\vec{E} \times \vec{B})$$

$$I = \frac{P}{A} = S_{\text{avg}} = \frac{c\epsilon_0}{2} E_0^2$$

$$p_{\text{rad}} = \frac{F}{A} = \frac{I}{c} \quad (\text{perfect absorber})$$

$$I = I_0 \cos^2 \theta$$

$$I_{\text{transmitted}} = \frac{1}{2} I_0 \quad (\text{incident light unpolarized})$$

Physical Constants

$$K = 8.99 \times 10^9 \text{ N} \cdot \text{m}^2/\text{C}^2$$

$$\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{N} \cdot \text{m}^2$$

$$e = 1.60 \times 10^{-19} \text{ C}$$

$$m_{\text{e}} = 9.11 \times 10^{-31} \text{ kg}$$

$$m_{\text{p}} = 1.67 \times 10^{-27} \text{ kg}$$

$$\mu_0 = 1.26 \times 10^{-6} \text{ T} \cdot \text{m/A}$$

$$c = 3.00 \times 10^8 \text{ m/s}$$

Useful Geometry

Circle

$$\text{Area} = \pi r^2$$

$$\text{Circumference} = 2\pi r$$

Sphere

$$\text{Surface area} = 4\pi r^2$$

$$\text{Volume} = \frac{4}{3}\pi r^3$$

Cylinder

$$\text{Lateral surface}$$

$$\text{area} = 2\pi rL$$

$$\text{Volume} = \pi r^2 L$$

PH2100 in Brief

$$\vec{F}_{\text{net}} = \sum_i \vec{F}_i = m\vec{a}$$

$$\vec{F}_{\text{A on B}} = -\vec{F}_{\text{B on A}}$$

Constant Acceleration :

$$x_{\text{f}} = x_{\text{i}} + v_{\text{ix}} \Delta t + \frac{1}{2} a_x (\Delta t)^2$$

$$y_{\text{f}} = y_{\text{i}} + v_{\text{iy}} \Delta t + \frac{1}{2} a_y (\Delta t)^2$$

$$v_{\text{fx}} = v_{\text{ix}} + a_x \Delta t$$

$$v_{\text{fy}} = v_{\text{iy}} + a_y \Delta t$$

$$v_{\text{fx}}^2 = v_{\text{ix}}^2 + 2a_x (x_{\text{f}} - x_{\text{i}})$$

$$v_{\text{fy}}^2 = v_{\text{iy}}^2 + 2a_y (y_{\text{f}} - y_{\text{i}})$$

Uniform Circular Motion :

$$v = \frac{2\pi r}{T} \quad \omega = \frac{2\pi \text{ rad}}{T}$$

$$\theta_{\text{f}} = \theta_{\text{i}} + \omega \Delta t$$

$$a_r = \frac{v^2}{r} = \omega^2 r$$

Energy Conservation

$$K = \frac{1}{2} mv^2$$

$$E_{\text{mech}} = K + U$$

$$K_{\text{f}} + U_{\text{f}} = K_{\text{i}} + U_{\text{i}}$$

$$P = \vec{F} \cdot \vec{v} = Fv \cos \theta$$