Electricity, Electromagnetism & Optics

$e = 1.602\times10^{-19}$, (C) $m_e = 9.11\times10^{-31}$, (kg) $m_p = 1.67\times10^{-27}$, (kg) $\varepsilon_o = 8.854\times10^{-12}$, (C^2/Nm^2)

$\kappa_o = \frac{1}{4\pi\varepsilon_o} = 8.988\times10^9 \cong 9\times10^9$, (Nm^2/C^2) $\kappa = \frac{1}{4\pi\varepsilon} = \frac{\kappa_o}{K}$ $K = \frac{\varepsilon}{\varepsilon_o}$ $(\kappa \neq K)$

$\boldsymbol{F_o} = \frac{\kappa_o Qq}{r_{c-c}^2}$, (N) $\boldsymbol{F_o} = q\boldsymbol{E_o}$, (N) $\boldsymbol{E_o} = \frac{\kappa_o Q}{r_{c-c}^2}$, (N/C) $\boldsymbol{E_o} = \boldsymbol{F_o}/q$, (N/C)

$\boldsymbol{F} = \frac{\boldsymbol{F_o}}{K} = \frac{\kappa Qq}{r_{c-c}^2}$, (N) $\boldsymbol{E} = \frac{\boldsymbol{E_o}}{K} = \frac{\kappa Q}{r_{c-c}^2}$, (N/C) $\boldsymbol{F} = q\boldsymbol{E}$, (N) $\boldsymbol{E} = \boldsymbol{F}/q$, (N/C)

$\boldsymbol{F_{net}} = \sum F_n$ $\boldsymbol{E_{net}} = \sum E_n$ $K_{free-space} = 1$ $K_{air} = 1.0006 \cong 1$ $K_{mica} = 7$ $K_{paraffin} = 2.2$ $K_{ethyl-alcohol} = 24$ $K_{water} = 80$

$\boldsymbol{a} = \frac{\boldsymbol{F}}{m}$, (m/s^2) $\boldsymbol{a} = \frac{q\boldsymbol{E}}{m}$, (m/s^2) $\boldsymbol{a} = \frac{(v^2 - v_o^2)}{2d}$, (m/s^2) $\boldsymbol{a} = \frac{(v - v_o)}{t}$, (m/s^2)

$\pm V_o = \frac{\kappa_o(\pm Q)}{r_{c-c}}$, (J/C) $\pm V = \frac{\pm V_o}{K} = \frac{\kappa(\pm Q)}{r_{c-c}}$, (J/C) $\pm V_{net} = \sum \pm V_n$, (J/C) $V_o = \boldsymbol{E_o} d$ $V = \boldsymbol{E} d$

$\pm(PE_{o,q}) = (\pm q)(\pm V_o)$ $\pm(PE_q) = (\pm q)(\pm V)$ $\pm(PE_{o,q}) = \frac{\kappa_o(\pm Q)(\pm q)}{r_{c-c}}$, (J) $\pm(PE_q) = \frac{\pm(PE_{o,q})}{K} = \frac{\kappa(\pm Q)(\pm q)}{r_{c-c}}$, (J) $\pm(PE_{o,q}) = (\pm q)(\boldsymbol{E_o} d)$ $\pm(PE_q) = (\pm q)(\boldsymbol{E} d)$

$\pm(\Delta V_o) = \kappa_o(\pm Q)\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$ $\pm(\Delta V) = \kappa(\pm Q)\left(\frac{1}{r_2} - \frac{1}{r_1}\right)$ $\pm(\Delta V_o) = \boldsymbol{E_o}(d_2 - d_1)$ $\pm(\Delta V) = \boldsymbol{E}(d_2 - d_1)$

$\pm(\Delta PE_{o,q}) = (\pm q)(\pm\Delta V_o)$ $\pm(\Delta PE_q) = (\pm q)(\pm\Delta V)$ $\pm(\Delta PE_{o,q}) = \kappa_o(\pm Q)\left(\frac{1}{r_2} - \frac{1}{r_1}\right)(\pm q)$ $\pm(\Delta PE_q) = \kappa(\pm Q)\left(\frac{1}{r_2} - \frac{1}{r_1}\right)(\pm q)$ $\pm(\Delta PE_{o,q}) = (\pm q) E_o(d_2 - d_1)$ $\pm(\Delta PE_q) = (\pm q) E(d_2 - d_1)$

$\pm W = \pm(\Delta PE_q)$ (J) $\pm W_{net} = \sum \pm W_n$ $\pm(\Delta PE_q) = \mp(\Delta KE)$, (J) $\pm W_{net} = (\pm(\Delta KE))$, (J) $qV = (1/2)mv^2$, (J)

$\boldsymbol{p} = (ql)$, (Cm) $V_{dipole} = \frac{\kappa \boldsymbol{p} \cos\theta}{r^2}$, (J/C) $1\text{eV} = 1.6\times10^{-19}$ Joule $1\text{ Joule} = 6.25\times10^{18}$ eV

$C_o = \frac{\varepsilon_o A}{d}$, (F) $C = KC_o = \frac{K\varepsilon_o A}{d} = \frac{\varepsilon A}{d}$, (F) $Q_o = C_o V_o = C_o \boldsymbol{E_o} d = \varepsilon_o A \boldsymbol{E_o}$, (C) $Q = CV = C\boldsymbol{E} d = \varepsilon A \boldsymbol{E}$, (C) $V' = \frac{Q_T}{C_T} = \frac{\Sigma(C_n V_n)}{\Sigma C_n}$ $Q_i' = C_i V'$

$U_E = \left(\frac{1}{2}\right)(QV)$ (J) $U_E = \left(\frac{1}{2}\right)(CV^2)$ $U_E = \frac{Q^2}{2C}$ $U_E = \left(\frac{\varepsilon E^2}{2}\right)(Ad)$ $u_E = \left(\frac{1}{2}\right)(\varepsilon E^2)$ (J/m^3)

$I = \frac{\Delta q}{\Delta t} = \frac{q}{t}$ (A) $V = RI$, (V) $R = \frac{\rho l}{A}$, (Ω) $R = \frac{1}{G}$ $R_T = R_{To}(1 + \alpha\Delta T)$ (Ω) $\Delta R = R_{To}\alpha\Delta T$

$I = nAev_d$, (A) $I = GV$, (A) $G = \frac{\sigma A}{l}$, (mho) $\rho = \frac{1}{\sigma}$ $\rho_T = \rho_{To}(1 + \alpha\Delta T)$ (Ωm) $\Delta\rho = \rho_{To}\alpha\Delta T$

$\rho_{cu} = 1.68\times10^{-8}$, (Ωm) $\rho_{Al} = 2.65\times10^{-8}$, (Ωm) $\rho_{Fe} = 9.71\times10^{-8}$, (Ωm) $\rho_{Tung} = 5.60\times10^{-8}$, (Ωm)

$\rho_{cu} = 8.9\times10^3$, (Kg/m^3) $\rho_{Al} = 2.7\times10^3$, (Kg/m^3) $\rho_{Fe} = 7.8\times10^3$, (Kg/m^3)

$P = VI = \frac{V^2}{R} = I^2R$, (watt) $\quad P_{loss} = I^2R$, (watt) $\quad$ 1 hp = 746 watts ≅ 750 watts

energy $= Pt = VIt = I^2Rt = (V^2/R)\,t$, (J) $\quad$ 1 KWh = 3.6×10^6, (J) $\quad$ 1 Ah = 3.6×10^3, (C)

$V_{inst} = V_p \sin\theta$, (V) $\quad I_{inst} = I_p \sin\theta$, (A) $\quad \theta = \omega t$, (rad) $\quad \omega = 2\pi f$, (rad/sec) $\quad f = \frac{1}{T}$, (1/sec)

$V_{rms} = \left(\frac{V_p}{\sqrt{2}}\right)$, (V) $\quad I_{rms} = \left(\frac{I_p}{\sqrt{2}}\right)$, (A) $\quad P_{av} = (V_{rms} I_{rms})$, (watt) $\quad P_p = 2P_{av} = (V_p I_p)$, (watt)

$V_{ab} = \varepsilon - Ir$, (V) $\quad V_{ab} = \varepsilon\left(1 - \frac{r}{R+r}\right)$ $\quad I = \frac{\varepsilon}{R_T}$, (A) $\quad I = \frac{V_{ab}}{R}$ $\quad \sum V_{batteries} = \sum I_n R_n$ $\quad \sum I_{in} = \sum I_{out}$

$R_{eff-series} = \sum_n (R_n)$, ($\Omega$) $\quad \frac{1}{R_{eff-parallel}} = \sum_n \left(\frac{1}{R_n}\right)$, ($1/\Omega$) $\quad R_{1,2-parallel} = \left(\frac{R_1 R_2}{R_1 + R_2}\right)$, ($\Omega$)

$\frac{1}{C_{eff-series}} = \sum_n \left(\frac{1}{C_n}\right)$, (1/F) $\quad C_{eff-parallel} = \sum_n (C_n)$, (F) $\quad C_{1,2-series} = \left(\frac{C_1 C_2}{C_1 + C_2}\right)$, (F)

$\varepsilon_x = \left(\frac{R_x}{R_s}\right)\varepsilon_s = \left(\frac{l_x}{l_s}\right)\varepsilon_s$, (V) $\quad R_x = \left(\frac{R_2}{R_1}\right)R_3 = \left(\frac{l_2}{l_1}\right)R_3$, ($\Omega$) $\quad RC = \tau$, (sec) $\quad I_{max} = I_S = V_S/R$ $\quad Q_{max} = Q_S = CV_S$

$V_{inst-charge} = V_{max}\left(1 - e^{-\frac{t}{RC}}\right)$, (V) $\quad Q_{inst-charge} = Q_{max}\left(1 - e^{-\frac{t}{RC}}\right)$, (C) $\quad I_{inst-charge} = I_{max} e^{-\frac{t}{RC}}$, (A) $\quad I_{max} = \frac{V_S}{R}$

$V_{inst-discharge} = V_{max}\, e^{-\frac{t}{RC}}$, (V) $\quad Q_{inst-discharge} = Q_{max}\, e^{-\frac{t}{RC}}$, (C) $\quad I_{inst-discharge} = -I_{max}\, e^{-\frac{t}{RC}}$, (A) $\quad Q_{max} = CV_S$

$V_G = I_G\, r_G$, (V) $\quad R_V = (V_{voltmeter} - V_G)/I_G$, ($\Omega$) $\quad R_A = V_G/(I_{ammeter} - I_G)$, ($\Omega$)

$V_2\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right) = \frac{V_s}{R_1}$ $\quad V_2\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{V_s}{R_1}$ $\quad I_S = V_2\left(\frac{1}{R_2} + \frac{1}{R_3}\right) = \frac{V_s - V_2}{R_1} = \frac{V_1}{R_1}$

$\boldsymbol{F}_B = qv\boldsymbol{B}\sin\theta$, (N) $\quad F = IlB\sin\theta$, (N) $\quad mv_\perp = q\boldsymbol{B}\,r$, (Kg.m/s) $\quad Pitch = \frac{2\pi r}{\tan\theta_0}$ $\quad v = \frac{2\pi r}{T}$

$\tau = (N\boldsymbol{B}A)I$, (Nm) $\quad \mu = NIA$ $\quad \tau = \mu\boldsymbol{B}$ $\quad v = \frac{\boldsymbol{E}}{\boldsymbol{B}}$, (m/s) $\quad m = \frac{q\boldsymbol{B}\boldsymbol{B}'r}{\boldsymbol{E}}$, (Kg) $\quad \Phi = \frac{N\boldsymbol{B}AI}{\kappa}$

$\varepsilon_{Hall} = \boldsymbol{E}_{Hall}\, l$, (V) $\quad \varepsilon_{Hall} = v_d \boldsymbol{B} l$, (V) $\quad v_d = \left(\frac{\boldsymbol{E}_{Hall}}{\boldsymbol{B}}\right)$, (m/s) $\quad I = nAev_d$, (A)

$n_{Cu} = 8.4342\times10^{28}$ (e/m^3) $\quad n_{Fe} = 8.4108\times10^{28}$ (e/m^3) $\quad n_{Al} = 6.0260\times10^{28}$ (e/m^3)

$\mu_o = \pi(4\times10^{-7})$, (Tm/A) $\quad \left(\frac{\mu_o}{2\pi}\right) = 2\times10^{-7}$, (Tm/A) $\quad l = (2\pi r)N$, (m) $\quad l$ = (perimeter) N, (m)

$\boldsymbol{B}_{siwire} = \left(\frac{\mu_o}{2\pi}\right)\left(\frac{I}{r}\right)$ (T) $\quad \boldsymbol{B}_{loops} = \frac{\mu_o NI}{2r}$, (T) $\quad \boldsymbol{B}_{coil} = \frac{\mu_o NI}{l}$, (T) $\quad \frac{\boldsymbol{F}}{l} = \left(\frac{\mu_o}{2\pi}\right)\frac{I_1 I_2}{d}$, (N/m)

$\Phi_B = BA\cos\phi$, (Tm^2) $\quad \varepsilon = -N\left(\frac{\Delta\Phi_B}{\Delta t}\right)$, (V) $\quad \varepsilon = Blv_\perp$, (V) $\quad P = Fv$ $\quad F = \frac{B^2 l^2 v}{R}$ $\quad \varepsilon = (N\boldsymbol{B}A)\,\omega\sin\theta$, (V) $\quad \varepsilon_o = (N\boldsymbol{B}A)\,\omega$, (V)

$\theta = \omega t = (2\pi f)\,t$ $\quad f = \frac{1}{T}$, (1/sec) $\quad \omega = \frac{(\#\,\text{rpm})\times 2\pi}{60}$ $\quad \frac{\varepsilon_{sec}}{\varepsilon_{pr}} = \frac{M}{L} = \frac{N_{sec}}{N_{pr}} = \frac{I_{pr}}{I_{sec}}$ $\quad \varepsilon_{sec} = -\frac{M\Delta I_{pr}}{\Delta t}$, (V) $\quad \varepsilon_{self} = V_L = -\frac{L\Delta I_{pr}}{\Delta t}$, (V)

$L_{coil} = \frac{NBA}{I} = \frac{N\Phi_B}{I}$, (H) $\quad L_{coil} = \frac{\mu_o N^2 A}{l}$, (H) $\quad U_{B,coil} = (1/2)LI^2 = \frac{B^2}{2\mu_o}(Al)$, (J) $\quad u_B = \frac{U_B}{\text{volume}} = \frac{B^2}{2\mu_o}$ (J/m^3)

$V_{ab} = \pm L(\Delta I/\Delta t) + RI_{inst}$ $\quad \Delta I/\Delta t = (I_{max} - I_{inst})/\tau$ $\quad M = (N_2 B_1 A_2)/I_1$ $\quad M = (\mu_o N_1 N_2 A)/l$

$\tau = \frac{L}{R}$, (sec) $\quad I_{inst-on} = I_{max}\left(1 - e^{-\frac{t}{L/R}}\right)$, (A) $\quad V_{inst-on} = V_{max} e^{-\frac{t}{L/R}}$, (V) $\quad t = -[\ln(1-f)]\tau$

$I_{inst-off} = I_{max} e^{-\frac{t}{L/R}}$, (A) $\quad V_{inst-off} = -V_{max} e^{-\frac{t}{L/R}}$, (V)

$\chi_L = (\omega L)$, (Ω) $\quad \chi_C = \left(\frac{1}{\omega C}\right)$, ($\Omega$) $\quad \omega = 2\pi f$ $\quad V_R = RI_R$, (V) $\quad V_L = \chi_L I_L$, (V) $\quad V_C = \chi_C I_C$, (V)

$Z = \sqrt{R^2 + (\chi_L - \chi_C)^2}$, (Ω) $\quad V_S = ZI_S$, (V) $\quad V_R = RI_S$, (V) $\quad V_L = \chi_L I_S$, (V) $\quad V_C = \chi_C I_S$, (V)

$V_S = \sqrt{V_R^2 + (V_L - V_C)^2}$, (V) $\quad P_{av} = I_{rms}^2 R$, (watt) $\quad P_{av} = I_{rms}^2 Z \cos\phi$, (watt)

$\cos\phi = \frac{R}{Z} = \frac{V_R}{V_S}$ $\quad \sin\phi = \frac{\chi_L - \chi_C}{Z} = \frac{V_L - V_C}{V_S}$ $\quad \tan\phi = \frac{\chi_L - \chi_C}{R} = \frac{V_L - V_C}{V_R}$

$f_o = \frac{1}{2\pi}\sqrt{\frac{1}{LC}}$, (Hz) $\quad Q = \frac{1}{R}\sqrt{\frac{L}{C}}$ $\quad U = (1/2) L I_{max}^2$, (J) $\quad U = (1/2) C V_{max}^2$, (J) $\quad U = \frac{Q_{max}^2}{2C}$, (J)

$c = \sqrt{\frac{1}{\varepsilon_o \mu_o}} = 2.998\times10^8 \cong 3\times10^8$, (m/s) $\quad c = f\lambda$, (m/s) $\quad E = hf$, (J) $\quad h = 6.63\times10^{-34}$, (Jsec)

$n = \frac{c}{v}$ $\quad n_{free-space} = 1$ $\quad n_{air} = 1.0003 \cong 1$ $\quad n_{water} = 1.33$ $\quad n_{crown-glass} = 1.52$

$n_{ethyl-alcohol} = 1.36$ $\quad n_{diamond} = 2.42$ $\quad n_{lucite} = 1.51$ $\quad n_{flint-glass} = 1.58$

$R + T + A = 1$ $\quad \theta_i = \theta_r$ $\quad \frac{\sin\theta_1}{\sin\theta_2} = \frac{n_2}{n_1} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$ $\quad n_1 \sin\theta_1 = n_2 \sin\theta_2$ $\quad n_1 \sin\theta_c = n_2$ $\quad \lambda_{medium} = \frac{\lambda_{air}}{n_{medium}}$ $\quad d_{medium} = \frac{d_{air}}{n_{medium}}$

$r = 2f$ $\quad \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$, (1/m) $\quad m = -\frac{d_i}{d_o} = \frac{h_i}{h_o}$ $\quad m = m_1 m_2$ $\quad d_{o2} = s - d_{i1}$, (m)

$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$

f: positive for converging devices, negative for diverging devices
h_o & h_i: positive above principal axis, negative below
d_o: positive on *light* side, negative on *opposite* side
d_i: (a) mirrors: positive on *light* side, negative on *opposite* side
(b) lenses: positive on *opposite* side, negative on *light* sides

$d\sin\theta = m\lambda$ bright $\quad d\sin\theta = (m + \frac{1}{2})\lambda$ dark

$d\cos\theta = \left(\frac{l}{x}\right)(m\lambda)$ bright $\quad d\cos\theta = \left(\frac{l}{x}\right)(m + \frac{1}{2})\lambda$ dark $\quad m = 1, 2, 3.......$ $\quad \tan\theta = \frac{x}{l}$

$D\sin\theta = m\lambda$, minima $\quad D\sin\theta = (m + \frac{1}{2})\lambda$, maxima $\quad m = 1, 2, 3.......$ $\quad \tan\theta = \frac{x}{l}$

$2t = m\lambda$, bright / dark $\quad 2t = (m + \frac{1}{2})\lambda$, dark / bright

$I_1 = \frac{1}{2}I_o$ $\quad I_2 = I_1 \cos^2\theta$ $\quad \tan\theta_p = \frac{n_2}{n_1}$