Units: SI system: kg (kilogram), m (meter), s (second), C (coulomb); $\mathcal{A}$ (ampere)=C/s, V (volt)=J/C, F (farad)=C/V, Ω (ohm)=V/$\mathcal{A}$. $1\,\mathrm{mm} = 10^{-3}\,\mathrm{m}$, $1\,\mathrm{cm} = 10^{-2}\,\mathrm{m}$, $1\,\mathrm{km} = 10^{3}\,\mathrm{m}$; 1 N (newton)=kg·m/s^2, 1 J (joule)=N · m = kg · m^2/s^2, 1 W (watt)=J/s; prefixes: m (milli) 10^{-3}, μ (micro) 10^{-6}, n (nano) 10^{-9}, p(pico) 10^{-12}, k (kilo) 10^3, M (mega) 10^6.
Constants: $g = 9.8\,\mathrm{m/s^2}$, $k_e = 9 * 10^9\,\mathrm{N\ m^2/C^2} = 1/(4\pi\epsilon_0)$, $\epsilon_0 = 8.85 * 10^{-12}\,\mathrm{C^2/(N\ m^2)}$, $\mu_0 = 4\pi * 10^{-7}\,T{-}m/A$. $e = -1.6 * 10^{-19}\,\mathrm{C}$, $m_e = 9.11 * 10^{-31}\,\mathrm{kg}$, $m_p \simeq m_n = 1.67 * 10^{-27}\,kg$
Volumes. Cylinder: $\pi R^2 h$, sphere: $\frac{4}{3}\pi R^3$, cone: $\frac{1}{3}\pi R^2 h$. **Areas:** Sphere: $4\pi R^2$, circle: πR^2.
Quadratic equation. $ax^2 + bx + c = 0\,,\ x = \left(-b \pm \sqrt{b^2 - 4ac}\right)/(2a)$
Derivatives/integrals. $\frac{d}{dx}x^n = nx^{n-1}\,,\ \frac{d}{dx}\sin x = \cos x\,,\ \frac{d}{dx}\cos x = -\sin x\,,\ \frac{d}{dx}e^{-ax} = -ae^{-ax}$; $\int x^n\,dx = \frac{1}{n+1}x^{n+1}$, $\int dx/x = \ln x$; $\int dx \Big/ \sqrt{a^2 + x^2} = \ln\left(x + \sqrt{a^2 + x^2}\right)$; $\int dx\,\left(a^2 + x^2\right)^{-\frac{3}{2}} = x/\left(a^2\sqrt{a^2 + x^2}\right)$; $\int x\,dx\,\left(a^2 + x^2\right)^{-\frac{3}{2}} = -1/\left(\sqrt{a^2 + x^2}\right)$; $\int \sin x\,dx = -\cos x$; $\int \cos x\,dx = \sin x$.
Vectors. If $\vec{c} = \vec{a} + \vec{b}$, then $c_x = a_x + b_x$, $c_y = a_y + b_y$, $c_z = a_z + b_z$ and $c = \sqrt{c_x^2 + c_y^2 + c_z^2}$. Dot product: $\vec{a}\cdot\vec{b} = a_x b_x + a_y b_y + a_z b_z = a * b * \cos\theta$. Cross product: $\hat{\imath} \times \hat{\jmath} = \hat{k}$, $\hat{\jmath} \times \hat{k} = \hat{\imath}$, $\hat{k} \times \hat{\imath} = \hat{\jmath}$; $\vec{A} \times \vec{B} = (A_y B_z - A_z B_y)\hat{\imath} + (A_z B_x - A_x B_z)\hat{\jmath} + (A_x B_y - A_y B_x)\hat{k}$; $\left|\vec{A} \times \vec{B}\right| = A * B * \sin\alpha$.

Coulombs Law: $F = k_e \frac{q_1 q_2}{r^2}$, r-distance between charges; in vector form $\vec{F} = k_e \frac{q_1 q_2}{r^2}\hat{r}$, $\hat{r} = \vec{r}/r$ - unit vector from charge q_1 to q_2, $k_e = 9 * 10^9$... Superposition: if charge q_1 acts on q_0 with $\vec{F}_{01}$, charge q_2 acts on q_0 with $\vec{F}_{02}$, etc., then $\vec{F}_{\text{net on } q_0} = \vec{F}_{01} + \vec{F}_{02} + \ldots$

Electric field. Definition: $\vec{E} = \vec{F}_0/q_0$ (charge q_0 is a "probe"). Field from a charge q: $E = k_e \frac{q}{r^2}$, r-distance between charge and observation point; in vector form $\vec{E} = k_e \frac{q}{r^2}\hat{r}$, $\hat{r} = \vec{r}/r$ - unit vector from charge q to the observation point, $k_e = 9 * 10^9$... Superposition: consider charges q_1, q_2, etc. and the observation point. If q_1 creates field $\vec{E}_1$ at the observation point, q_2 creates field $\vec{E}_2$, etc., then $\vec{E} = \vec{E}_1 + \vec{E}_2 + \ldots$.
Force on a charge placed in external field $\vec{E}$: $\vec{F} = q\vec{E}$.

Gauss Law. Flux through a small area A with $\vec{A}$ along the normal to the surface: $\Phi = \vec{E}\cdot\vec{A}$. Flux through a closed surface: $\oint \vec{E}\cdot d\vec{A} = q_{\text{enc}}/\epsilon_0$. Field $E(r)$ from a uniformly charged spherical shell with radius R and charge Q: $E(r < R) = 0$, $E(r > R) = k_e Q/r^2$. Field $E(r)$ from a uniformly charged infinite line with linear charge density λ: $E(r) = \lambda/(2\pi\epsilon_0 r) = 2k_e\lambda/r$. Field E from a uniformly charged infinite non-conducting plane with surface charge density σ: $E = \sigma/(2\epsilon_0) = 2\pi k_e\sigma$.

Potential. Definition: $V = U/q_0$. Work: $W_{AB} = U_A - U_B = -q\Delta V$. Two charges: $U = k_e q_1 q_2/r$. Point charge: $V(r) = k_e q/r$. Superposition: $V(\vec{r}) = k_e\,(q_1/r_1 + q_2/r_2 + \ldots)$ (with r_1 - distance from q_1 to observation point, etc.). Potential from field: $V_B - V_A = -\int_A^B \vec{E}\cdot d\vec{s}$; for uniform field: $\Delta V = -Ed$. Field from potential: $E_x = -dV/dx, \ldots$. Conducting sphere with charge Q and radius R: $V(r) = k_e Q/r$, $r \geq R$ and $V(r) = k_e Q/R$, $r \leq R$.

Conductors. Inside the body of a conductor: $\vec{E} = 0$, V =const, no charge. Extra charge - goes to outer surface. Field near the surface of a conductor, *outside*, is $E = \sigma/\epsilon_0$; potential - continuous. Inner surfaces (surfaces of cavities) - uncharged, unless an extra charge is placed inside a cavity.

Capacitors. Definition: $C = Q/V$. Single sphere: $C = 4\pi\epsilon_0 R$. Spherical: $C = 4\pi\epsilon_0 R_1 R_2/(R_2 - R_1)$. Parallel plate capacitor: $C = A\epsilon_0\kappa/d$. Energy: $U_C = Q^2/(2C) = V^2C/2$. Connections: parallel (same voltage) $C_{eq} = C_1 + C_2 + \ldots$; series (same charge) $1/C_{eq} = 1/C_1 + 1/C_2 + \ldots$ or $C_{eq} = C_1C_2/(C_1 + C_2)$ (for two only). $Q_{\text{tot}} = VC_{eq}$.

Current. Definitions: current $I = \Delta q/\Delta t \simeq dq/dt$, density of current $J = I/A$, with A - cross-sectional area. Ohm's law: $I = V/R$ with R-resistance. For wire of length L: $R = \rho L/A$, with ρ - resistivity of material. $J = E/\rho$. Power: $P = IV = I^2R = V^2/R$. Simple connections: series (same current) $R_{eq} = R_1 + R_2 + \ldots$; parallel (same voltage) $1/R_{eq} = 1/R_1 + 1/R_2 + \ldots$ or $R_{eq} = R_1R_2/(R_1 + R_2)$ (for two only). Microscopic picture: $J = env_d$.

Multiloop circuits and Kirchoff's equations. Potential changes: $+\mathcal{E}$ when crossing battery from negative to positive terminal; $-IR$ when traveling through a resistor along the current. Loop equation: potential drop around a close loop is zero. Junction equation: sum of incoming currents equals sum of outgoing currents.
Charging a capacitor: $q(t) = \mathcal{E}C\left(1 - e^{-t/\tau}\right)$ with $\tau = RC$; $V_C(t) = \frac{q}{C} = \mathcal{E}\left(1 - e^{-t/\tau}\right)$, $i(t) = i_{\max}e^{-t/\tau}$ with $i_{\max} = \frac{\mathcal{E}}{R}$. Discharging a capacitor: $\tau = RC$, $q(t) = Q_0e^{-t/\tau}$, $V(t) = V_0e^{-t/\tau}$ with $V_0 = \frac{Q_0}{C}$; $i(t) = i_0e^{-t/\tau}$ with $i_0 = \frac{Q_0}{RC}$.

Magnetic force. Force on a particle: $\vec{F}_m = q\vec{v} \times \vec{B}$. Revolution in magnetic field: radius $r = mv/(qB)$, period $T = 2\pi m/(qB)$. Force on a wire: $\vec{F}_w = I\vec{L} \times \vec{B}$. Interaction between two parallel wires: $F = \mu_0 I_1 I_2 L/(2\pi d)$ with $\mu_0 = 4\pi * 10^{-7}$. Magnetic moment for a coil with N turns: $\vec{\mu} = NI\vec{A}$; potential energy: $U = -\vec{\mu} \cdot \vec{B}$; torque $\vec{\tau} = \vec{\mu} \times \vec{B}$.

Fields from currents. Straight wire: $B = \mu_0 I/(2\pi d)$. Bio-Savarat: $d\vec{B} = (\mu_0/4\pi)Id\vec{s} \times \vec{r}/r^3$. At the center of ring current of radius R: $B_{\text{ring}} = \mu_0 I/(2R)$; for a circular arc with angle θ (in radians): $B = B_{\text{ring}} \times \theta/(2\pi)$. Amper's Law: $\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{\text{enc}}$. Field in a solenoid: $B = \mu_0 In$, with n - density of turns.

Electromagnetic induction (Faraday Law). EMF $\mathcal{E} = -d\Phi_B/dt$. $\Phi_B \simeq \vec{A} \cdot \vec{B}$. If area A=const, $\mathcal{E} = -A\,dB/dt$; if B =const, $\mathcal{E} = -B\,dA/dt$; moving rod: $\mathcal{E} = lvB$. Induced current: $I_{\text{ind}} = \mathcal{E}/R$. Direction (Lenz rule): the flux due to induced current tries to oppose the changes in the original flux. **Self-induction**. Magnetic flux through a conductor with current I: $\Phi = LI$, L-inductance. For a solenoid with length l, cross-sectional area A and density of turns n, one has $L/l = \mu_0 An^2$. Self-induced EMF: $\mathcal{E}_L = -L\,dI/dt$. Energy: $U_L = \frac{1}{2}LI^2$. $\oint \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$ $\quad \mathcal{E} = \int (\vec{v} \times \vec{B}) \cdot d\vec{l}$

RL circuits. Time constant $\tau_L = L/R$. Decay of current $I(t) = I_0 \exp(-t/\tau_L)$. Build up of current $I(t) = \mathcal{E}/R * [1 - \exp(-t/\tau_L)]$. At $t = 0$ inductor acts as infinite resistance; at $t \to \infty$ acts as a piece of wire.

LC and driven LRC circuits. Free oscillations in LC circuit: natural (or resonant) frequency $\omega_0 = 1/\sqrt{LC}$ (in rad/s) or $f_0 = \omega_0/(2\pi)$ (in Hz). Energy conservation: $\frac{1}{2}q^2/C + \frac{1}{2}Li^2$ =const or $\frac{1}{2}Q_{\max}^2/C = \frac{1}{2}LI_{\max}^2$. **Driven**: f_d (in Hz) - driving frequency; $\omega_d = 2\pi f_d$. Inductive reactance: $X_L = \omega_d L$; capacitive reactance: $X_C = 1/(\omega_d C)$. Impedance $Z = \sqrt{R^2 + (X_L - X_C)^2}$. Amplitude of current: $I_m = \mathcal{E}_m/Z$. Phase angle: $\tan\phi = (X_L - X_C)/R$. Resonance: $\omega_d = \omega_0$, $X_L = X_C$, $Z = R = \min$, $I_m = \mathcal{E}_m/R = \max$. RMS values: $I_{RMS} = I_m/\sqrt{2}$, $V_{RMS} = \mathcal{E}_m/\sqrt{2}$; $I_{RMS} = V_{RMS}/Z$. Power $P = I_{RMS}^2 R$.
Transformers: $V_2 = V_1 * N_2/N_1$, $I_2 = I_1 * N_1/N_2$.

From Phys 111:
Kinematics: $v = dx/dt$, $a = dv/dt = d^2x/dt^2$. Circular motion with constant speed: $\omega = v/R$, $a_c = v^2/R = \omega^2 R$, towards center.
The three Laws of motion: (1) If $\vec{F}_{net} = 0$ then $\vec{v} = const$; (2) $\vec{F}_{net} = m\vec{a}$; (3) $\vec{F}_{21} = -\vec{F}_{12}$
Work and power. $W_{AB} = \int_A^B \vec{F} \cdot d\vec{r}$. Power: $P = W/\Delta t = \vec{F} \cdot \vec{v}$.
Kinetic energy and work-energy theorem: $K = \frac{1}{2}mv^2$, $\Delta K = W$ where W is the *net* work (i.e. work by all forces).
Potential energy. For conservative forces (with path-independent work) introduce $U(\vec{r})$ so that $W_{AB} = U_A - U_B = -\Delta U$. If *only* conservative forces, then energy conservation: $K + U = const$.