Inside the body of a conductor:

- Product: $a \times b + c = 0$, $x = \left(-b \pm \sqrt{b^2 - 4ac}\right)/(2a)$
- Integrals: $\int x^n dx = \frac{1}{n+1}x^{n+1}$, $\int dx/x = \ln x$;
- Electric field: $\vec{F} = k_c \frac{q_1 q_2}{r^2} \hat{r}$, $\hat{r} = \hat{r}/r$ = unit vector from charge $q_1$ to $q_2$.
- Coulomb's Law: $F = k_e \frac{q_1 q_2}{r^2}$, $r$-distance between charges; in vector form $\vec{F} = k_e \frac{q_1 q_2}{r^2} \hat{r}$, $\hat{r} = \hat{r}/r$ = unit vector from charge $q_1$ to $q_2$.
- Electric field density: $\vec{E} = \vec{E}_0/q_0$ (charge $q_0$ is a "probe").
- Gaussian Law: Flux through a closed surface: $\hat{\Phi} \cdot \hat{A} = q_{enc}/\epsilon_0$. Field $\vec{E}(r)$ 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 $\lambda$: $E(r) = \lambda/(2\pi \epsilon_0 r)$ = $2k_e \lambda/r$. Field $E$ from a uniformly charged infinite non-conducting plane with surface charge density $\sigma$: $E = \sigma/(2\epsilon_0) = 2\pi k_e \sigma$.

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: $V(r) = k_e (q_1/r_1 + q_2/r_2 + \ldots)$ (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: $E_x = -dV/dx$. 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: $C = 4\pi\varepsilon_0 R$. Spherical: $C = 4\pi\varepsilon_0 R_1 R_2/(R_2 - R_1)$. Parallel plate capacitor: $C = \varepsilon_0 \kappa /d$. 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 $C_{eq} = C_1 C_2/(C_1 + C_2)$ (for two only). $Q_{tot} = V C_{eq}$.

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 $\rho$ - resistivity of material. $J = E/p$. 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 $R_{eq} = R_1 R_2/(R_1 + R_2)$ (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: $q(t) = \mathcal{E}C(1 - e^{-t/\tau})$ with $\tau = RC$; $V_C(t) = q/C = \mathcal{E}(1 - e^{-t/\tau})$, $i(t) = i_{max} e^{-t/\tau}$ with $i_{max} = \mathcal{E}/C$. Discharging a capacitor: $\tau = RC$, $q(t) = Q_0 e^{-t/\tau}$, $V(t) = V_0 e^{-t/\tau}$ with $V_0 = Q_0/C$, $i(t) = i_0 e^{-t/\tau}$ with $i_0 = \mathcal{E}/RC$.

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 $\mu_0 = 4\pi \times 10^{-7}$. Magnetic moment for a coil with $N$ turns: $\vec{\mu} = NI\vec{A}$; potential energy: $U = -\vec{\mu} \cdot \vec{B}$; torque $\tau = \vec{\mu} \times \vec{B}$.

Fields from currents. Straight wire: $B = \mu_0 I/(2\pi d)$. Bio-Savarat: $d\vec{B} = (\mu_0/4\pi)l ds \times \vec{\sigma}/r^3$. At the center of ring current of radius $R$: $B_{ring} = \mu_0 I/(2R)$; for a circular arc with angle $\theta$ (in radians): $B = B_{ring} \times \theta/(2\pi)$. Amper’s Law: $\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{enc}$. 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: $\mathcal{E} = I v B$. Induced current: $I_{ind} = \mathcal{E}/R$. 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: $U_L = 1/2 LI^2$.

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: $1/2 C V^2 + \frac{1}{2} L I^2 = \text{const}$ or $1/2 Q_{max}^2/C = 1/2 L_{max}^2$. 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: $\omega_d = \omega_0$, $X_L = X_C$, $Z = R = \text{min}$, $I_m = \mathcal{E}_m/R = \text{max}$. 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: $V_2 = V_1 \times N_2/N_1$, $I_2 = I_1 \times N_1/N_2$. 

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From Phys 111:

**Kinematics:** \( v = dx/dt, \quad a = dv/dt = d^2x/dt^2 \). Circular motion with constant speed:
\( \omega = v/R, \quad a_c = v^2/R = \omega^2R, \) towards center.

**The three Laws of motion:** (1) If \( \vec{F}_{net} = 0 \) then \( \vec{v} = \text{const} \); (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: \( K + U = \text{const} \).