Permittivity of free space: $\epsilon_0 = 8.854 \times 10^{-12}$
Elementary charge: $e = 1.602 \cdot 10^{-19}$
Proton mass: $1.673 \cdot 10^{-27}$
Electron mass: $9.11 \cdot 10^{-31}$
Speed of light: $c = 3 \cdot 10^8$
Permeability constant: $\mu_0 = 1.26 \times 10^{-6}$

Moving Conductor

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

$$F_{\text{mag}} = F_{\text{pull}} = IlB = \frac{vl^2B^2}{R}$$

$$P_{\text{input}} = P_{\text{dissipated}} = I^2R = \frac{v^2l^2B^2}{R}$$

$$\Phi_m = \vec{A} \cdot \vec{B} = |A||B|\cos\theta \quad \text{(uniform magnetic field)}$$

- Increasing flux: The induced magnetic field points opposite the applied magnetic field.
- Decreasing flux: The induced magnetic field points in the same direction as the applied magnetic field.
- Steady flux: There is no induced magnetic field.

$$\varepsilon_{\text{induced}} = \frac{d\Phi_m}{dt} \quad I_{\text{induced}} = \frac{\varepsilon_{\text{induced}}}{R}$$

$$E_{\text{inside}} = \frac{r}{2}\left|\frac{dB}{dt}\right| \quad \text{Solenoid}$$

$$\frac{V_2}{V_1} = \frac{N_2}{N_1} \quad \text{Transformers}$$

Inductors

$$L = \frac{\Phi_m}{I} \text{ henry (H)}$$

$$\Delta V_L = -L\frac{dI}{dt} \quad U_L = L\int_0^I IdI = \frac{1}{2}LI^2$$

LC Circuits

$$I = -\frac{dQ}{dt} \quad Q(t) = Q_0\cos\omega t$$

$$\omega = \frac{1}{\sqrt{LC}} \quad f = \omega/2\pi$$

LR Circuits

$$I = I_0e^{-t/(L/R)}$$

$$\tau = \frac{L}{R} \quad \text{where current has decreased to } e^{-1}$$

Right-hand rule (wire)

1. Point thumb in the direction of current
2. Point fingers in the direction of magnetic field
3. Point palm in the face of force on wire

$$\vec{E}_B = \vec{E}_A + \vec{v}_{BA} \times \vec{B}_A$$

$$\vec{B}_B = \vec{B}_A - \frac{1}{c^2}\vec{v}_{BA} \times \vec{E}_A$$

$$a \times b = \begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix}$$

$$I_{\text{disp}} = \epsilon_0\frac{d\Phi_e}{dt} = \epsilon_0\frac{dE \cdot A}{dt}$$

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{in}}}{\epsilon_0} \quad \text{Gauss's Law}$$

$$\oint \vec{B} \cdot d\vec{A} = 0 \quad \text{Gauss's Law for Magnetism}$$

$$\oint \vec{E} \cdot d\vec{s} = -\frac{d\Phi_m}{dt} \quad \text{Faraday's Law}$$

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{\text{through}} + \epsilon_0\mu_0\frac{d\Phi_e}{dt} \quad \text{Ampere-Maxwell Law}$$

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B}) \quad \text{Lorentz Force Law}$$

$$E(x,t) = E_0\cos(kx - \omega t + \phi)$$

1. $k = \frac{2\pi}{\lambda}$ where k is wave number and λ is wavelength
2. $T = \frac{2\pi}{\omega}$ where T is period and ω is angular frequency
3. $f = \frac{1}{T}$ where f is frequency
4. $v = f\lambda$ where v is the propagation speed
5. $v = \frac{E_0}{B_0}$ where E_0 and B_0 are the electric and magnetic field components

$$E = cB$$

$$I = \frac{P}{4\pi r^2} = \frac{c\epsilon_0E_0^2}{2}$$

$$\langle S\rangle = \frac{1}{\mu_0}EB\sin\theta$$

Right-hand rule (electromagnetic waves)

1. Point index finger in the direction of electric field
2. Point middle finger in the direction of magnetic field
3. Point thumb in the direction of motion

$$I_{\text{transmitted}} = \frac{1}{2}I_0 \quad \text{unpolarized}$$

$$I_{\text{transmitted}} = I_0\cos^2\theta \quad \text{polarized}$$

$$\varepsilon = \varepsilon_0\cos\omega t \quad \omega = 2\pi f$$

$$v_R = i_RR \quad \text{(AC circuit) and } V_R \text{ is the maximum voltage}$$

Capacitor circuit

$$v_C = V_C\cos\omega t$$

$$q = Cv_C$$

$$i_C = -\omega CV_C\sin\omega t = \omega CV_C\cos(\omega t + \frac{\pi}{2})$$

$$X_C = \frac{1}{\omega C} \quad I_C = \frac{V_C}{X_C} \quad (X_C \text{ is Capacitive reactance})$$

$$\omega_C = \frac{1}{RC} \quad \text{(RC Circuit)}$$

Inductor circuit

$$i_L = I_L\cos(\omega t - \frac{\pi}{2})$$

$$X_L = \omega L \quad I_L = \frac{V_L}{X_L} \quad (X_L \text{ is Inductive reactance})$$

Series RLC Circuit

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \quad \text{(impedance)}$$

$$I_{\text{peak}} = \frac{\varepsilon_0}{Z}$$

$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right) \quad \text{(angle between emf and current)}$$

$$\omega_0 = \frac{1}{\sqrt{LC}} \quad \text{(resonance frequency)}$$

- If $V_C > V_L$, the circuit operates below resonance frequency
- If $V_L > V_C$, the circuit operates above resonance frequency

$$p = i\varepsilon \quad \text{(AC circuit)}$$

i and ε are instantaneous current and potential difference

$$P_R = \frac{1}{2}I_R^2R = I_{\text{rms}}V_{\text{rms}}$$

$$x_{\text{rms}} = \frac{x}{\sqrt{2}}$$

$$P_{\text{source}} = \frac{1}{2}I\varepsilon_0\cos\phi = I_{\text{rms}}\varepsilon_{\text{rms}}\cos\phi = P_{\max}\cos^2\phi$$

$\cos\phi$ is the power factor, ϕ is the phase between current and emf, $P_{\text{mas}} = \frac{1}{2}I_{\max}\varepsilon_0$.
In an AC circuit with a capacitor, the current leads the voltage by $\frac{\pi}{2}$ so current reaches maximum $\frac{T}{4}$ before voltage.
In an AC circuit with an inductor, the current lags the voltage by $\frac{\pi}{2}$ so current reaches maximum $\frac{T}{4}$ after voltage.