Things to Know for the Final

Constants	**Particle**	charge	mass	**Charge density**
$c = \frac{1}{\sqrt{\varepsilon_0\mu_0}} = 2.998 \times 10^8$ m/s				
$k_e = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^9$ N m^2/C^2	electron	-1.60×10^{-19} C	9.11×10^{-31} kg	$\lambda = \frac{q}{L}$ (line)
$\varepsilon_0 = 8.885 \times 10^{-12}$C^2/Nm^2	proton	$+1.60 \times 10^{-19}$ C	1.67×10^{-27} kg	$\sigma = \frac{q}{A}$ (surface)
$N_0 = 6.02 \times 10^{23}$ particles/mole	neutron	0 C	1.67×10^{-27} kg	$\rho = \frac{q}{V}$ (volume)
$\mu_0 = 12.566 \times 10^{-7}$ NA^{-2}				

$\vec{F} = k_e \frac{q_1 q_2}{r^2}\hat{r}$	$\Delta U = -q_0 \int_A^B \vec{E} \cdot d\vec{r}$	$U = \frac{q^2}{2C} = \frac{1}{2}CV^2$	$\vec{F} = q\vec{v} \times \vec{B}$	$\Phi_B = \int \vec{B} \cdot d\vec{A}$
$\vec{E} = \frac{\vec{F}}{q_0}$	$U = k_e \frac{q_1 q_2}{r_{12}}$	$u_E = \frac{1}{2}\varepsilon_0 E^2$	$\vec{F} = I\vec{\ell} \times \vec{B}$	$L = \frac{\Phi_B}{I}$
$\vec{E} = k_e \sum_i \frac{q_i}{r_i^2}\hat{r}_i$	$\Delta V = \frac{\Delta U}{q_0}$ with $V_\infty = 0$	$I \equiv \frac{dq}{dt} = nav_d A$	$\frac{F}{\ell} = \mu_0 \frac{I_1 I_2}{2\pi d}$	$\varepsilon_L = -L\frac{dI}{dt}$
$\vec{E} = k_e \int \frac{dq}{r^2}\hat{r}$	$V = k_e \sum_i \frac{q_i}{r_i} = k_e \int \frac{dq}{r}$	$j \equiv \frac{I}{A} = \sigma E$	$\vec{B} = \frac{\mu_0}{4\pi} \int \frac{I d\vec{\ell} \times \vec{r}}{r^2}$	$U = \frac{1}{2}LI^2$
$\Phi = \int_{\text{surface}} \vec{E} \cdot d\vec{A}$	$C \equiv \frac{q}{V}$ and $C = \kappa C_0$	$R = \frac{V}{I} = \rho\frac{L}{A}, \rho = \frac{1}{\sigma}$	$\oint \vec{E} \cdot d\vec{\ell} = -\frac{d\Phi_B}{dt}$	$u_B = \frac{1}{2\mu_0}B^2$
$\Phi = \oint \vec{E} \cdot d\vec{A} = \frac{q_{\text{in}}}{\varepsilon_0}$	$P = \frac{dU}{dt} = IV = RI^2$	$R = \frac{mv}{qB}$	$\oint \vec{B} \cdot d\vec{\ell} = \mu_0 I_{\text{enc.}}$	$U = \int u_B dV$

component	reactance	series	parallel	**Kirchoff's laws**
resistance	$X_R = R$	$R_{\text{tot}} = \sum_i R_i$	$\frac{1}{R_{\text{tot}}} = \sum_i \frac{1}{R_i}$	1- $\sum_i V_i = 0$ (closed loop)
capacitance	$X_C = 1/\omega C$	$\frac{1}{C_{\text{tot}}} = \sum_i \frac{1}{C_i}$	$C_{\text{tot}} = \sum_i C_i$	2- $I_{\text{in}} = \sum I_{\text{out}}$ (at a node)
inductance	$X_L = \omega L$	$L_{\text{tot}} = \sum_i L_i$	$\frac{1}{L_{\text{tot}}} = \sum_i \frac{1}{L_i}$	

RC circuit (DC)		**RL circuit (DC)**	
charging	discharging	ε on	ε off
$q = C\varepsilon(1 - e^{-t/RC})$	$q = C\varepsilon e^{-t/RC}$	$I = \frac{\varepsilon}{R}(1 - e^{-Rt/L})$	$I = \frac{\varepsilon}{R}e^{-Rt/L}$
$I = \frac{dq}{dt} = \frac{\varepsilon}{R}e^{-t/RC}$	$I = \frac{dq}{dt} = -\frac{\varepsilon}{R}e^{-t/RC}$	$V_L = L\frac{dI}{dt} = \varepsilon e^{-Rt/L}$	$V_L = L\frac{dI}{dt} = -\varepsilon e^{-Rt/L}$

<u>AC circuits</u>: $I_{\text{rms}} = \frac{I_{\max}}{\sqrt{2}}$, $\varepsilon_{\text{rms}} = \frac{\varepsilon_{\max}}{\sqrt{2}}$, and $\langle P \rangle = I_{\text{rms}}\varepsilon_{\text{rms}}\cos\phi$ where $\cos\phi = \frac{R}{Z}$

Type	impedance Z	**Resonance**		**Transformers**	
RC	$\sqrt{R^2 + X_C^2}$	$\omega_0 = \frac{1}{\sqrt{LC}}$	resonance frequency	$V_2 = \frac{N_2}{N_1}V_1$	(no load)
RL	$\sqrt{R^2 + X_L^2}$	$Q = \frac{\omega_0}{\Delta\omega} = \frac{\omega_0 L}{R}$	Q-factor	$i_2 = \frac{N_2}{N_1}i_1$	(with load)
RLC	$\sqrt{R^2 + (X_L - X_C)^2}$	$\langle P \rangle = \frac{\varepsilon_{\text{rms}}^2}{R}\frac{x^2}{x^2 + Q^2(x^2-1)^2}$	power (with $x = \omega/\omega_0$)	$\langle P(\omega_0 \pm \frac{\Delta\omega}{2}) \rangle = \frac{1}{2}\langle P \rangle_{\max}$	

Maxwell's equations		**Dipoles**			
$\oint \vec{E} \cdot d\vec{A} = \frac{q}{\varepsilon_0}$	$\oint \vec{E} \cdot d\vec{\ell} = -\frac{d\Phi_B}{dt}$	electric	$p = qd$	$\vec{\tau} = \vec{p} \times \vec{E}$	$U = -\vec{p} \cdot \vec{E}$
$\oint \vec{B} \cdot d\vec{A} = 0$	$\oint \vec{B} \cdot d\vec{\ell} = \mu_0 I + \varepsilon_0\mu_0\frac{d\Phi_E}{dt}$	magnetic	$\mu = IA$	$\vec{\tau} = \vec{\mu} \times \vec{B}$	$U = -\vec{\mu} \cdot \vec{B}$

Electromagnetic waves (e.g., $E_x = E_0\sin(kz - \omega t)$)			**Reflection/Refraction/Optics**	
$v = \frac{\omega}{k} = \lambda f$,	$E_0 = cB_0$ (in vacuum),	$u = u_E + u_B$ (with $u_E = u_B$)	$n = c/v$,	$n_1\sin\theta_1 = n_2\sin\theta_2$
$\vec{S} = \frac{1}{\mu_0}\vec{E} \times \vec{B}$,	$S = \frac{1}{\mu_0}EB$,	$\langle S \rangle = \frac{1}{2}\frac{E_0^2}{\mu_0 c} = \frac{c}{2}\frac{B_0^2}{\mu_0} = I$	$\theta_i = \theta_r$,	$\sin\theta_c = n_{\text{lower}}/n_{\text{higher}}$
$P = I/c$ (absorbing surface)		$P = 2I/c$ (reflecting surface)	$\frac{1}{o} + \frac{1}{i} = \frac{1}{f}$,	$M = -\frac{i}{o} = \frac{h'}{h}$, $f = \frac{R}{2}$

Double slits	**Single slit**	**Gratings**	**Thin film**
$\Delta P \approx d\sin\theta = m\lambda$: bright	$a\sin\theta = m\lambda$: dark ($m \neq 0$)	$d\sin\theta = m\lambda$: bright	$2tn = (m + \frac{1}{2})\lambda$: bright
$d\sin\theta = (m + \frac{1}{2})\lambda$: dark	$\theta_{\min} = 1.22\lambda/D$	$R = \lambda/\Delta\lambda = mN$	$2tn = m\lambda$: dark
$I = I_{\max}\cos^2\left(\frac{\pi d\sin\theta}{\lambda}\right)$	$I = I_{\max}\left[\frac{\sin[\pi a\sin(\theta)/\lambda]}{\pi a\sin(\theta)/\lambda}\right]^2$	**Reflection** in n_1 between n_1 and n_2	180^o phase change ($n_1 < n_2$) 0^o phase change ($n_1 > n_2$)