Physics 1402 - Formula List - Final

- **Constants**

$k_e = \frac{1}{4\pi\varepsilon_0} = 9.0\times10^9\ \frac{\text{N·m}^2}{\text{C}^2}$ $\varepsilon_0 = 8.85\times10^{-12}\ \frac{\text{C}}{\text{N·m}^2}$

$e = 1.60\times10^{-19}$ C $\mu_0 = 4\pi\times10^{-7}$ N/A^2

$m_{\text{electron}} = 9.11\times10^{-31}$ kg $m_{\text{proton}} = m_{\text{neutron}} = 1.67\times10^{-27}$ kg

$h = 6.63\times10^{-34}$ J·s $c = 3.00\times10^8$ m/s

1 eV = 1.60×10^{-19} J $R = 1.097\times10^7\ \text{m}^{-1}$

- **Geometry**

Circle: $c = 2\pi r$ $A = \pi r^2$

Sphere: $A = 4\pi r^2$ $V = \frac{4}{3}\pi r^3$

Cylinder: $A = 2\pi r L$ $V = \pi r^2 L$

- **Metric Prefixes** $G = 10^9$, $M = 10^6$, $k = 10^3$, $c = 10^{-2}$, $m = 10^{-3}$, $\mu = 10^{-6}$, $n = 10^{-9}$, $p = 10^{-12}$, $f = 10^{-15}$

- **Coulomb's Law** $F = k_e \frac{|q_1|\cdot|q_2|}{r^2}$ (magnitude of force)

Charge quantization: $Q = n\,e$, n is an integer.

- **Electric Field** $\vec{E} = \vec{F}/q_0$, $\vec{F} = q\,\vec{E}$ (force on q)

Point Charge: $E = k_e \frac{|q|}{r^2}$ (mag) or $E_r = k_e \frac{q}{r^2}$ (radial comp.)

Discrete: $\vec{E} = \vec{E}_1 + \vec{E}_2 + \ldots$, where $\vec{E}_1$ is due to q_1, etc.

- **Electric Flux** $\Phi = \sum E_\perp A$ (small A), uniform $\vec{E}$ and flat A: $\Phi = E_\perp A$
- **Gauss's Law** $\Phi = \frac{1}{\varepsilon_0} q_{\text{enclosed}}$ (closed surface)

Spherical Dist.: $E_r = \frac{1}{4\pi\varepsilon_0}\frac{q_{\text{enclosed}}}{r^2} = k_e \frac{q_{\text{enclosed}}}{r^2}$

Infinite Plane: $E = \frac{\sigma}{2\varepsilon_0}$

- **Charge Densities:** $\lambda = \frac{\text{charge}}{\text{length}} \Longleftrightarrow$ charge $= \lambda\times$(some length)

$\sigma = \frac{\text{charge}}{\text{area}} \Longleftrightarrow$ charge $= \sigma\times$(some area)

$\rho = \frac{\text{charge}}{\text{volume}} \Longleftrightarrow$ charge $= \lambda\times$(some volume)

- **Potential and Potential Energy** $V = U/q_0$, $\Delta U = q\,\Delta V$

For two charges: $U = k_e \frac{q_i\,q_j}{r}$

Conservation of Energy: $K_i + U_i = K_f + U_f$, where $K = \frac{1}{2} m v^2$

- **Potential due to Charges** Point Charge: $V = k_e \frac{q}{r}$

Discrete: $V = V_1 + V_2 + \ldots$, where V_1 is due to q_1, etc.

- **Potential and Electric Field** $\Delta V = -\sum E_\parallel \Delta s$ (small Δs)

$\Delta V = -E_\parallel \Delta s$ (uniform $\vec{E}$), $E_\parallel = -\frac{\Delta V}{\Delta s}$ (small Δs)

- **Conductors in Electrostatics** At surface: $\vec{E} \perp$ surface and $E = \sigma/\varepsilon_0$

Inside: $\vec{E} = \vec{0}$, voltage is const., no excess charge.

- **Capacitance** $Q = C\,V$, C is the capacitance. $C_0 = \frac{\varepsilon_0 A}{d}$ (∥ Plate)

$C = \kappa\,C_0$, where C_0 = empty cap. and dielectric const. $= \kappa \geq 1$

- **Energy** $U = \frac{1}{2} C V^2 = \frac{Q^2}{2C} = \frac{1}{2} Q\,V$ (energy in a cap.)

$u_E = \frac{\varepsilon_0}{2} E^2 = \frac{\text{Energy}}{\text{Volume}}$ (energy density in a field)

- **Current** $I = \frac{\Delta Q}{\Delta t}$ (current through surface)
- **Ohm's Law** $V = I\,R$, $R = \frac{\rho L}{A}$, ρ = resistivity
- **Power** $\mathcal{P} = V\,I$, For a resistor: $\mathcal{P} = V\,I = I^2 R = \frac{V^2}{R}$
- **Combinations of Resistors**

Series: $R_{\text{eq}} = R_1 + R_2 + \ldots$, Parallel: $\frac{1}{R_{\text{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots$

- **Combinations of Capacitors**

Series: $\frac{1}{C_{\text{eq}}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots$, Parallel: $C_{\text{eq}} = C_1 + C_2 + \ldots$

- **Kirchhoff's Rules** Junctions: $\sum I_{\text{in}} = \sum I_{\text{out}}$, Loops: $0 = \sum \Delta V$
- **RC Circuits** $\tau = R\,C$ = time const., $\mathcal{E}$ = EMF

Discharging: $Q(t) = Q_0\, e^{-t/\tau}$ and $I(t) = -\frac{Q_0}{\tau} e^{-t/\tau}$

Charging: $Q(t) = C\,\mathcal{E}\left(1 - e^{-t/\tau}\right)$ and $I(t) = \frac{\mathcal{E}}{R} e^{-t/\tau}$

- **Magnetic Force on Particle and Wire**

$F = |q|\,v\,B\sin\theta = |q|\,v_\perp B = |q|\,v\,B_\perp$

$F = ILB\sin\theta = ILB_\perp$

$\vec{v} \perp$ to uniform $\vec{B} \Longrightarrow$ circle with $r = \frac{m\,v}{|q|\,B}$

- **Ampere's Law** $\sum B_\parallel \Delta s = \mu_0 I_{\text{enclosed}}$ ($\Delta\vec{s}$ is small)

$B = \frac{\mu_0 I}{2\pi r}$ (distance r from long wire)

$B = \frac{\mu_0 I}{2R}$ (center of current loop)

$B = \mu_0\, n\, I$, $n = \frac{\text{\# of turns}}{\text{length}}$ (inside long solenoid)

- **Torque** $\tau = N\,I\,A\,B\sin\theta = N\,I\,A\,B_\perp$(on N-turn Coil)
- **Magnetic Flux** $\Phi = \sum B_\perp A$

For uniform field and flat surface: $\Phi = B_\perp A = BA\cos\theta$

- **Faraday's Law** $\mathcal{E} = -N\frac{\Delta\Phi}{\Delta t}$ (small Δt) , $\mathcal{E}_{\text{ave}} = -N\frac{\Delta\Phi}{\Delta t}$

AC Generator: $\Phi = B\,A\cos\omega t \Longrightarrow \mathcal{E}(t) = N\,B\,A\,\omega\sin\omega t$

- **Motional EMF**

moving rod: $\mathcal{E} = B\,\ell\,v$ $\left(\vec{B} \perp \vec{v} \perp \text{rod}\right)$

- **Lenz's Law**

Choose a pos. dir. for normal to loop
Sign of Φ is + if field in + dir. thru loop.
$\frac{\Delta\Phi}{\Delta t}$ has same (opposite) sign as Φ when incr. (decr.).
Φ_{induced} sign is opposite to that of $\frac{\Delta\Phi}{\Delta t}$.
Get direction of $\mathcal{E}$ or I by Right Hand Rule.

- **Inductance** $\mathcal{E} = -L\frac{\Delta I}{\Delta t}$ (small Δt)

Long Solenoid: $L = \mu_0 \frac{N^2}{\ell} A$

Energy in Inductor: $U = \frac{1}{2} L I^2$

- **Energy Density** $u = \frac{1}{2\mu_0} B^2$ (in magnetic field)

$u = u_E + u_B = \frac{\varepsilon_0}{2} E^2 + \frac{1}{2\mu_0} B^2$ (in electromagnetic field)

- **RL Circuits** $\tau = \frac{L}{R}$ = time const.

Current Growth: $I(t) = \frac{\mathcal{E}}{R}\left(1 - e^{-t/\tau}\right)$, Current Decay: $I(t) = I_0\, e^{-t/\tau}$

- **Transformer** $\frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$
- **LC Circuits** $\omega_0 = \frac{1}{\sqrt{LC}}$, $Q(t) = Q_0 \cos(\omega_0 t)$, $I(t) = -\omega Q_0 \sin(\omega_0 t)$
- **General AC Circuits** $V_{rms} = \frac{1}{\sqrt{2}} V_{max}$, $I_{rms} = \frac{1}{\sqrt{2}} I_{max}$

$\omega = 2\pi f$, $I(t) = I_{max} \sin \omega t$, $V(t) = V_{max} \sin(\omega t + \phi)$

$Z = \frac{V_{max}}{I_{max}} = \frac{V_{rms}}{I_{rms}}$ (Impedance), $\mathcal{P}_{ave} = V_{rms} I_{rms} \cos\phi$

	Z	ϕ
R	R	0
L	$X_L = \omega L = 2\pi f L$	$90° = \frac{\pi}{2}$
C	$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$	$-90° = -\frac{\pi}{2}$

- **Series RCL** $Z = \sqrt{R^2 + (X_L - X_C)^2}$, $\tan\phi = \frac{X_L - X_C}{R}$

$\mathcal{P}_{ave} = I_{rms}^2 R$, No $L \Rightarrow X_L = 0$, No $C \Rightarrow X_C = 0$

Resonance: $Z = Z_{min} = R \iff X_L = X_C \iff \omega = \frac{1}{\sqrt{LC}}$

- **Electromagnetic Radiation in Vacuum**

$f\lambda = c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = \frac{E_{max}}{B_{max}} = \frac{E_{rms}}{B_{rms}} = \frac{E}{B}$

Energy density: $u_{ave} = \frac{\varepsilon_0}{2} E_{max}^2 = \frac{B_{max}^2}{2\mu_0} = \varepsilon_0 E_{rms}^2 = \frac{B_{rms}^2}{\mu_0}$

Intensity: $I = \frac{\text{Power}}{\text{Area}} = \frac{U}{A\,\Delta t}$, $I = u_{ave}\, c = \frac{\varepsilon_0 c}{2} E_{max}^2 = \varepsilon_0 c E_{rms}^2$

- **Radiation Pressure and Momentum**

Momentum carried by radiation: $p = \frac{U}{c}$, Pressure $= \frac{\text{Force}}{\text{Area}}$

	Momentum to Surface	Pressure on Surface
Perfect Absorber	$p = \frac{U}{c}$	Pressure $= \frac{I}{c}$
Perfect Reflector	$p = 2\frac{U}{c}$	Pressure $= 2\frac{I}{c}$

- **Polarization** $I = \frac{1}{2} I_0$, $I = I_0 \cos^2\theta$
- **In a Medium** $f\lambda = v = c/n$

At interface: $n_1 \lambda_1 = n_2 \lambda_2$ $f_1 = f_2$
Snell's Law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

Total Internal Refl.: $\theta_1 > \theta_{crit}$ where $\sin\theta_{crit} = \frac{n_2}{n_1}$

- **Geometric Optics** $\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$, $m = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$

Sph. Mirrors: $f = \frac{R}{2}$, $R > 0$ (concave), $R < 0$ (convex), $R \to \infty$ (flat)

Thin Lenses: $f > 0$ (converging), $f < 0$ (diverging)

- **Interference and Diffraction** $\tan\theta = \frac{y}{L}$

Double Slit: Const.Int. : $d\sin\theta = m\lambda$, Dest.Int. : $d\sin\theta = \left(m + \frac{1}{2}\right)\lambda$

Diffraction Grating: Const. Int.: $d\sin\theta = m\lambda$, Dest. Int. elsewhere

Single Slit: Dest. Int.: $W\sin\theta = m\lambda$, $m \neq 0$

- **Relativity** Lorentz factor: $\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$

$v = c\sqrt{1 - \frac{1}{\gamma^2}}$ ($v << c \Longrightarrow \gamma \simeq 1 + \frac{1}{2}\frac{v^2}{c^2}$)

Time Dilation: $\Delta t = \gamma\,\Delta t_0 = \frac{\Delta t_0}{\sqrt{1 - v^2/c^2}}$, Δt_0 is the proper time

Length Contraction: $L = \frac{L_0}{\gamma} = L_0\sqrt{1 - v^2/c^2}$, L_0 is the proper length

Addition of velocities: $v_{23} = \frac{v_{21} + v_{13}}{1 + v_{21} v_{13}/c^2}$

Relativistic Mass: $m_r = \gamma\, m_0 = \frac{m_0}{\sqrt{1 - v^2/c^2}}$, m_0 is the rest mass

Energy of a Particle: $E = m_r c^2 = \gamma\, m_0 c^2$, $E_0 = m_0 c^2$ = rest energy

Kinetic Energy: $K = E - E_0 = (\gamma - 1)\, m_0 c^2 = \left(\frac{1}{\sqrt{1 - v^2/c^2}} - 1\right) m_0 c^2$

Mass/Energy Equivalence: $E = m_r c^2$, $\Delta m = \Delta E / c^2$

Momentum: $p = m_r v = \gamma\, m_0 v = \frac{m_0 v}{\sqrt{1 - v^2/c^2}}$ ($m_0 = 0 \Longrightarrow p = m_r c = \frac{E}{c}$)

- **Quantum Physics**

Wien Law: $\lambda_{peak} = (0.00290\ \text{m}\cdot\text{K})/T$

Photon hypothesis: $E = hf$ (Energy of a photon)

Photoelectric Effect: $K_{max} = hf - W_0$ and $K_{max} = eV_0$

Compton Effect: $\Delta\lambda = \lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta)$ where $\frac{h}{m_e c} = 2.43 \times 10^{-12}$ m

de Broglie Wavelength: $\lambda = h/p$ Uncertainty Principle: $\Delta x\, \Delta p_x \geq \frac{h}{4\pi}$

- **Atomic Physics** Hydrogen Spectrum: $\frac{1}{\lambda} = R\left(\frac{1}{n'^2} - \frac{1}{n^2}\right)$

Bohr Atom: $L_n = r_n m_e v_n = n\frac{h}{2\pi}$, $r_n = a_0 \frac{n^2}{Z}$, $E_n = -E_0 \frac{Z^2}{n^2}$

where $a_0 = 5.29 \times 10^{-11}$ m $E_0 = 2.18 \times 10^{-18}$ J = 13.6 eV

Quantum #s: $n = 1, 2, \ldots$ $\ell = 0, 1, \ldots, n - 1$ $m_\ell = 0, \pm 1, \ldots, \pm\ell$ $m_s = \pm\frac{1}{2}$

Spectroscopic Notation: $0 \to s, 1 \to p, 2 \to d, 3 \to f$

- **Nuclear Physics** $\text{u} = \frac{1}{12}\text{mass}(^{12}_{6}\text{C}) = 1.66 \times 10^{-27}$ kg (atomic mass unit)

Size of the nucleus: $r = 1.2\ \text{fm} \times A^{1/3}$ where fm $= 10^{-15}$ m

Decay: $N(t) = N_0 e^{-\lambda t} = N_0 2^{-t/T_{1/2}}$ where $\lambda = \ln(2)/T_{1/2} = 0.691/T_{1/2}$