Physics 182 Equation Sheet for Exams

- **Good Stuff from 181:**
Kinematics: $\vec{v} = \frac{d\vec{r}}{dt}$; $\vec{a} = \frac{d\vec{v}}{dt}$; ($\vec{a} = const : x = x_0 + v_0\Delta t + \frac{1}{2}a\Delta t^2$; $v = v_0 + a\Delta t$; $v^2 = v_0^2 + 2a\Delta x$)
Dynamics: $\vec{F} = m\vec{a}$ UCM: $\vec{a}_r = (\frac{v^2}{r}$, toward center)
Conservation of Energy: $\Delta E_{mech} = \Delta K + \Delta U = W_{nc}$; $K = \frac{1}{2}mv^2$; $U_{\text{grav}} = mgy$; $U_{\text{spring}} = \frac{1}{2}kx^2$
Gravity: $\vec{F}_g = (\frac{Gm_1m_2}{r^2}$, attractive) $U_g = \frac{-Gm_1m_2}{r}$

- **Chapter 18:**
Moles : $n = \frac{M}{M_{mol}} = \frac{N}{N_A}$ Ideal Gas : $PV = nRT = Nk_BT$ $k_B = \frac{R}{N_A}$
Temperatures: $T_F = \frac{9}{5}T_C + 32°$ $T_K = T_C + 273$
Pressure: $P_{\text{atm}} = 1.013 \times 10^5\ Pa = 1.0\ atm$ Hydrostatic: $P(\text{at d}) = P_0 + \rho g d$
Thermal Expansion: $\frac{\Delta L}{L} = \alpha\Delta T$ $\frac{\Delta V}{V} = \beta\Delta T$

- **Chapter 19:**
Work:

$$\begin{aligned} W(\underline{\text{on}}\text{ the system}) &= -\int_{V_i}^{V_f} P\ dV = -(\text{area under PV curve}) \quad (\text{general}) \\ &= -P\Delta V \quad (\text{isobaric}) \\ &= -nRT\ln\left(\frac{V_f}{V_i}\right) \quad (\text{isothermal}) \\ &= -\left[\frac{P_fV_f - P_iV_i}{(1-\gamma)}\right] \quad (\text{adiabatic}) \end{aligned}$$

First Law: Solids/Liquids: $\Delta E_{th} = Q = Mc\Delta T$ $Q_f = \pm ML_f$ $Q_v = \pm ML_v$
First Law: Gases: $\Delta E_{th} = Q + W$
Specific Heats: (constant volume) $Q = nC_V\Delta T$ (constant pressure) $Q = nC_P\Delta T$
(any process) $\Delta E_{th} = nC_V\Delta T$ $C_P = C_V + R$
Adiabatic Process: $Q = 0$ $PV^\gamma = constant$ $TV^{\gamma-1} = constant$ $\gamma = C_P/C_V$
Heat Transfer: Conduction: $\frac{Q}{\Delta t} = k\frac{A}{L}\Delta T$ Radiation: $\frac{Q_{emit}}{\Delta t} = e\sigma AT^4$ $\frac{Q_{net}}{\Delta t} = e\sigma A(T^4 - T_0^4)$

- **Chapter 20:**
Mean Free Path: $\lambda = \frac{1}{4\sqrt{2}\pi(N/V)r^2}$ $r \approx .5 \times 10^{-10}\ m$(monatomic), $r \approx 1 \times 10^{-10}\ m$(diatomic)
Kinetic Theory: $P = \frac{1}{3}(\frac{N}{V})mv_{rms}^2 = \frac{2}{3}(\frac{N}{V})\epsilon_{avg}$ $\epsilon_{avg} = \frac{1}{2}mv_{rms}^2 = \frac{3}{2}k_BT$ $v_{rms} = \sqrt{\frac{3k_BT}{m}}$
Discrete distribution: $v_{mp} = v$ at maximum $v_{\text{avg}} = \frac{1}{N}\sum_{i=1}^{n_{\text{bins}}} v_iN_i$ $v_{\text{rms}} = \left[\frac{1}{N}\sum_{i=1}^{n_{\text{bins}}} v_i^2N_i\right]^{1/2}$
Continuous distribution: v for N_v maximum $v_{\text{avg}} = \frac{1}{N}\int_0^\infty vN_vdv$ $v_{\text{rms}} = \left[\frac{1}{N}\int_0^\infty v^2N_vdv\right]^{1/2}$
Ideal Gases: $E_{th} = nC_VT$
Monatomic: $C_V = \frac{3}{2}R$ $C_P = \frac{5}{2}R$ $\gamma = \frac{C_P}{C_V} = \frac{5}{3}$
Diatomic: $C_V = \frac{5}{2}R$ $C_P = \frac{7}{2}R$ $\gamma = \frac{C_P}{C_V} = \frac{7}{5}$
Solids: $E_{th} = nCT$ $C = 3R$

- **Chapter 21:**
Work done <u>by</u> the system: $W_s = -W(\text{on the system}) = +\int PdV$
Heat Engine: $Q_H = Q_C + W_{out}$ $\eta = \frac{W_{out}}{Q_H} = 1 - \frac{Q_C}{Q_H}$ $\eta_{Carnot} = 1 - \frac{T_C}{T_H}$
Refrigerator: $W_{in} + Q_C = Q_H$ $K = \frac{Q_C}{W_{in}} = \frac{Q_C}{Q_H - Q_C}$ $K_{Carnot} = \frac{T_C}{T_H - T_C}$

- **Chapter 22:**
Coulomb Law: $|F_{q_1 q_2}| = K\frac{|q_1||q_2|}{r^2} = \frac{1}{4\pi\epsilon_0}\frac{|q_1||q_2|}{r^2}$
Charge in a Field: $\vec{F} = q\vec{E}$
Field of a Point Charge q: $\vec{E} = K\frac{q}{r^2}\hat{r} = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}\hat{r}$

- **Chapter 23:**
Dipole Moment: $\vec{p} = (qs, \text{from } -\text{q to} + \text{q})$ $\vec{E}(\text{on axis} \parallel \vec{p}) \approx \frac{2K\vec{p}}{r^3}$ $\vec{E}(\text{on axis} \perp \vec{p}) \approx -\frac{K\vec{p}}{r^3}$
Continuous Charge Distribution Q: $d\vec{E} = K\frac{dq}{r^2}\hat{r}$ $\vec{E} = \int_Q d\vec{E}$
Charge Densities: $1\text{D} : \lambda = Q/L$ $2\text{D} : \eta = Q/A$ $3\text{D} : \rho = Q/V$
Special Field Results: Infinite Wire: $\vec{E} = (\frac{2K|\lambda|}{r};$ away for $\lambda > 0,$ toward for $\lambda < 0)$
Infinite Plane: $\vec{E} = (\frac{|\eta|}{2\epsilon_0};$ away for $\eta > 0,$ toward for $\eta < 0)$
Parallel Plate Capacitor: $\vec{E} = (\frac{\eta}{\epsilon_0},$ positive to negative)
Ring of Charge: $E_z = \frac{1}{4\pi\epsilon_0}\frac{zQ}{(z^2+R^2)^{3/2}}$
Disk of Charge: $E_z = \frac{\eta}{2\epsilon_0}\left[1 - \frac{z}{\sqrt{z^2+R^2}}\right]$
Torque on a Dipole: $\vec{\tau} = \vec{p} \times \vec{E}$ or $|\vec{\tau}| = pE\sin\theta$ (Direction by RHR)

- **Chapter 24:**
Flux through Surface S: $\Phi_e = \int_S \vec{E} \cdot d\vec{A}$
Special Cases: Planar surface & uniform $\vec{E}$: $\Phi_e = \vec{E} \cdot \vec{A}$
Planar surface $\perp$ uniform $\vec{E}$: $\Phi_e = EA$
Gauss' Law: For closed surface S: $\Phi_e = \oint_S \vec{E} \cdot d\vec{A} = \frac{Q_{in}}{\epsilon_0}$
Some Geometry: Cylinder (radius r, length L): $A = 2\pi rL + 2\pi r^2;$ $V = \pi r^2 L$
Sphere (radius r): $A = 4\pi r^2;$ $V = \frac{4}{3}\pi r^3$

- **Chapter 25:**
Electric Potential Energy: Uniform field: $U = qEs$ point charges: $U = \frac{kq_1q_2}{r} = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r}$
Electric Potential Energy of a dipole in a uniform field: $U_{\text{dipole}} = -\vec{p} \cdot \vec{E} = -pE\cos\phi$
Electric Potential: $V = \frac{U}{q}$ $\Delta V = -\int \vec{E} \cdot d\vec{s}$
Special Cases: Uniform $\vec{E}$: $\Delta V = -\vec{E} \cdot \vec{s}$ Point Charge: $V = \frac{kq}{r} = \frac{1}{4\pi\epsilon_0}\frac{q}{r}$
Continuous Distribution: $dV = \frac{kdq}{r}$

- **Chapter 26:**
Field and Potential: $\Delta V = V_B - V_A = -\int_A^B \vec{E} \cdot d\vec{s}$ $E_x = -\partial V/\partial x$ $E_y = -\partial V/\partial y$ $E_z = -\partial V/\partial z$
Capacitors: $C = \frac{Q}{\Delta V}$ Parallel Plate: $C = \frac{\epsilon_0 A}{d}$ Energy: $U_c = \frac{Q^2}{2C} = \frac{1}{2}C(\Delta V)^2$
Energy Density: $u_E = \frac{1}{2}\epsilon_0 E^2$
Combinations: Parallel: $C = C_1 + C_2$ Series: $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$ Dielectric: $C = \kappa C_0$ $E = \frac{E_0}{\kappa}$

- **Chapter 27:**
Electron Current: $i_e = n_e A v_d$ $v_d = \frac{eE}{m_e}\tau$ $i_e = \frac{n_e e \tau A}{m_e}E$
Current: $\vec{I} = (dQ/dt,$ direction of $\vec{\text{E}})$ $I = ei_e = JA$ $J = n_e e v_d$
$\vec{J} = \sigma\vec{E} = \vec{E}/\rho$ $\sigma = \frac{1}{\rho} = \frac{n_e e^2 \tau}{m_e}$
Conservation of Current: Current is the same at any point along the wire.
Resistance: $R = \rho\frac{L}{A}$ Ohm's Law: $I = \frac{\Delta V}{R}$

- **Chapter 28:**
Kirchoff's Laws Junction: $\sum I_{in} = \sum I_{out}$ Closed Loop: $\sum_i (\Delta V)_i = 0$
Conventions: EMF: $\Delta V = \pm\mathcal{E}\begin{pmatrix}\text{from } - \to + \\ \text{from } + \to -\end{pmatrix}$ Resistor: $\Delta V = \mp IR\begin{pmatrix}\text{with I} \\ \text{against I}\end{pmatrix}$
Power: $P_{bat} = I\mathcal{E}$ $P_R = I^2R = \frac{(\Delta V)^2}{R} = I\Delta V$
Combinations: Series: $R = R_1 + R_2$ Parallel: $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$
RC Circuit: Discharging: $Q(t) = Q_0 e^{-t/\tau}$ $I(t) = I_0 e^{-t/\tau}$ $\tau = RC$ $Q_0 = C\Delta V_0$ $I_0 = \frac{\Delta V_0}{R}$
Charging: $Q(t) = Q_{max}(1 - e^{-t/\tau})$ $I(t) = \frac{\mathcal{E}}{R}e^{-t/\tau}$ $Q_{max} = C\mathcal{E}$

- **Chapter 29:**
Vector Cross Product: $\vec{C} = \vec{A} \times \vec{B} = (AB\sin\theta, \text{direction by RHR})$
Or: $\vec{C} = \vec{A} \times \vec{B} = \begin{vmatrix} \hat{\imath} & \hat{\jmath} & \hat{k} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix} = \hat{\imath}(A_yB_z - A_zB_y) - \hat{\jmath}(A_xB_z - A_zB_x) + \hat{k}(A_xB_y - A_yB_x)$
Biot–Savart Law: Charge: $\vec{B} = \frac{\mu_0}{4\pi}\frac{q\vec{v}\times\hat{r}}{r^2}$ Current: $d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{s}\times\hat{r}}{r^2}$
Ampere's Law: $\oint \vec{B}\cdot d\vec{s} = \mu_0 I_{\text{thru}}$
Field of an Infinite Straight Wire: $B = \frac{\mu_0 I}{2\pi r}$ Field of an Ideal Solenoid: $B = \frac{\mu_0 NI}{L}$
Field of a Current Loop: $B(z) = \frac{\mu_0}{2}\frac{IR^2}{(z^2+R^2)^{3/2}}$
Magnetic Dipole Moment: $\vec{\mu} = (AI$, South pole to North pole (RHR)$)$ Field: $\vec{B}_{\text{dipole}} \approx \frac{\mu_0}{4\pi}\frac{2\vec{\mu}}{z^3}$
Magnetic Forces: on a Charge: $\vec{F} = q\vec{v}\times\vec{B}$ on a wire : $d\vec{F} = Id\vec{s}\times\vec{B}$
on a straight wire in uniform field: $\vec{F} = I\vec{L}\times\vec{B}$
Cyclotron Motion: $r_{\text{cyc}} = \frac{mv}{qB}$ $f_{\text{cyc}} = \frac{qB}{2\pi m}$
Force between parallel wires: $\vec{F} = \left[\frac{\mu_0 L I_1 I_2}{2\pi d}, \begin{pmatrix} \text{attractive for parallel} \\ \text{repsulsive for anti} - \text{parallel} \end{pmatrix}\right]$
Torque on a Dipole: $\vec{\tau} = \vec{\mu}\times\vec{B}$ or $|\vec{\tau}| = \mu B\sin\theta$ (Direction by RHR)

- **Chapter 30:**
Magnetic Flux: $\Phi_m = \int \vec{B}\cdot d\vec{A}$ Faraday's Law: $\mathcal{E} = |\frac{d\Phi_m}{dt}|$
Lenz's Law: The direction of the induced current is such that the induced magnetic field opposes the change in flux.
Faraday's Law for Fields: $\oint \vec{E}\cdot d\vec{s} = -\frac{d}{dt}\int \vec{B}\cdot d\vec{A}$

- **Chapter 31:**
Transformation of Fields for frame S' moving relative to S at constant speed V along x-axis:
$\vec{E'} = \vec{E} + \vec{v}\times\vec{B}$ $\vec{B'} = \vec{B} - \epsilon_0\mu_0\vec{v}\times\vec{E}$
(inverse: interchange primes and unprimes, replace $\vec{v}$ with $-\vec{v}$)
Maxwell's Equations:
$\oint \vec{E}\cdot d\vec{A} = \frac{Q_{in}}{\epsilon_0}$ $\oint \vec{B}\cdot d\vec{A} = 0$ $\oint \vec{E}\cdot d\vec{s} = -\frac{d}{dt}\int \vec{B}\cdot d\vec{A}$ $\oint \vec{B}\cdot d\vec{s} = \mu_0 I_{thru} + \epsilon_0\mu_0\frac{d}{dt}\int \vec{E}\cdot d\vec{A}$
Lorentz Force Law: $\vec{F} = q\vec{E} + q\vec{v}\times\vec{B}$

- **Chapter 36:**
Galilean Transformations for frame S' moving relative to S at constant speed v along x-axis:

$$\text{Coordinates}: \; x = x' + vt' \;\; ; \;\; y = y' \;\; ; \;\; z = z' \;\; ; \;\; t = t'$$
$$\text{Velocity Components}: \; u_x = u'_x + v \;\; ; \;\; u_y = u'_y \;\; ; \;\; u_z = u'_z$$

Lorentz Transformations for frame S' moving relative to S at constant speed v along x-axis:

$$\text{Coordinates}: \; x = \gamma(x' + vt') \;\; ; \;\; y = y' \;\; ; \;\; z = z' \;\; ; \;\; t = \gamma(t' + \frac{vx'}{c^2})$$
$$\text{Velocity Components}: \; u_x = \frac{u'_x + v}{1 + \frac{vu'_x}{c^2}} \;\; ; \;\; u_y = \frac{u'_y}{\gamma(1 + \frac{vu'_x}{c^2})} \;\; ; \;\; u_z = \frac{u'_z}{\gamma(1 + \frac{vu'_x}{c^2})}$$

where:
$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

(For inverse transformations: interchange unprimed quantities with primed and change v to $-v$.)

Length Contraction and Time Dilation:
$$L_p = \gamma L \;\; ; \;\; \Delta t = \gamma \Delta t_p$$

Dynamics:
$$\vec{p} = \gamma_p m\vec{u} \;\; ; \;\; E = K + mc^2 = \gamma_p mc^2 \;\; ; \;\; K = (\gamma_p - 1)mc^2 \;\; ; \;\; E^2 = p^2c^2 + m^2c^4$$