

## FORMULA SHEET

- Vectors:

$$\vec{A} \cdot \vec{B} = AB \cos \theta$$

$$|\vec{A} \times \vec{B}| = AB \sin \theta$$

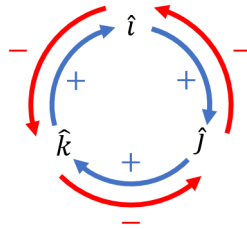


Figure 1: Cyclic permutations for cross product

- Kinematics:

$$g = 9.8 \text{ m/s}^2$$

$$\Delta x = v_0 t + \frac{1}{2} a t^2$$

$$v = v_0 + a t$$

$$v^2 = v_0^2 + 2 a \Delta x$$

- Forces:

$$\sum \vec{F} = m \vec{a}$$

$$W = m g$$

$$f_{s, \max} = \mu_s N$$

$$f_k = \mu_k N$$

- Circular Motion:

$$a_c = \frac{v^2}{r}$$

$$v = \frac{2\pi r}{T}$$

- Gravity:

$$G = 6.67 \times 10^{-11} \frac{\text{Nm}^2}{\text{kg}^2}$$

$$F_g = G \frac{mM}{r^2}$$

$$a_g = G \frac{M}{r^2}$$

$$T^2 = \frac{4\pi^2}{GM} a^3 \quad (\text{Kepler's third law})$$

- Work & Energy:

$$K = \frac{1}{2}mv^2$$

$$U_g = mgy \quad (\text{near Earth's surface})$$

$$U_g = -G\frac{mM}{r} \quad (\text{anywhere})$$

$$W = F\Delta x \cos \theta$$

$$W_{tot} = \Delta K$$

$$W_{cons} = -\Delta U$$

$$W_{other} = \Delta E$$

$$K_i + U_i + W_{other} = K_f + U_f$$

$$P = \frac{\Delta E}{\Delta t}$$

$$P = Fv \quad (\text{at constant velocity})$$

- Linear Momentum:

$$\vec{p} = m\vec{v}$$

$$\sum \vec{F}_{ext,sys} = \frac{\Delta \vec{p}_{sys}}{\Delta t}$$

$$m_1\vec{v}_{1i} + m_2\vec{v}_{2i} = m_1\vec{v}_{1f} + m_2\vec{v}_{2f}$$

$$v_{1i} - v_{2i} = v_{2f} - v_{1f} \quad (\text{elastic collisions})$$

$$\vec{J} = \vec{F}_{av}\Delta t \quad (\text{impulse})$$

- Rotational Motion:

- Rotational Kinematics:

$$\Delta\theta = \omega_0 t + \frac{1}{2}\alpha t^2$$

$$\omega = \omega_0 + \alpha t$$

$$\omega^2 = \omega_0^2 + 2\alpha\Delta\theta$$

- Rolling without slipping:

$$\Delta x = R\Delta\theta$$

$$v = R\omega$$

$$a = R\alpha$$

- Rotational Dynamics:

$$\tau = rF \sin \theta$$

$$\Delta\tau = I\alpha = \frac{\Delta L}{\Delta t}$$

$$K_{rot} = \frac{1}{2}I\omega^2$$

$$L = I\omega = rp$$

- Rotational Motion (continued):

- Moment of inertia:

$$I = mr^2 \text{ (point mass)}$$



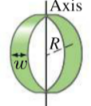



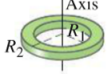
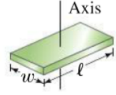
(a) <b>Thin hoop,</b> radius $R$	Through center		$MR^2$	(e) <b>Uniform sphere,</b> radius $R$	Through center		$\frac{2}{5}MR^2$
(b) <b>Thin hoop,</b> radius $R$ width $w$	Through central diameter		$\frac{1}{2}MR^2 + \frac{1}{12}Mw^2$	(f) <b>Long uniform rod,</b> length $\ell$	Through center		$\frac{1}{12}M\ell^2$
(c) <b>Solid cylinder,</b> radius $R$	Through center		$\frac{1}{2}MR^2$	(g) <b>Long uniform rod,</b> length $\ell$	Through end		$\frac{1}{3}M\ell^2$
(d) <b>Hollow cylinder,</b> inner radius $R_1$ outer radius $R_2$	Through center		$\frac{1}{2}M(R_1^2 + R_2^2)$	(h) <b>Rectangular thin plate,</b> length $\ell$ , width $w$	Through center		$\frac{1}{12}M(\ell^2 + w^2)$

Figure 2: Moments of Inertia of Rigid Objects

- Fluids:

$$\rho_{H_2O} = 1000 \frac{\text{kg}}{\text{m}^3}$$

$$P = \frac{F}{A}$$

$$P_f = \rho_f g D$$

$$B = \rho_f g V_{sub}$$

$$\frac{V_{sub}}{V_{obj}} = \frac{\rho_{obj}}{\rho_f}$$

$$A_1 v_1 = A_2 v_2$$

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$$

- Oscillations:

$$F_{sp} = -kx$$

$$U_{sp} = \frac{1}{2}kx^2$$

$$E = U_{max} = K_{max}$$

$$\omega = 2\pi f$$

$$\omega_{sp} = \sqrt{\frac{k}{m}}$$

$$\omega_{pend} = \sqrt{\frac{g}{l}}$$

- Waves & Sound:

$$v_{\text{sound}} = 350 \text{ m/s}$$

$$I_0 = 10^{-12} \frac{\text{W}}{\text{m}^2}$$

$$v = \lambda f$$

$$v = \sqrt{\frac{T}{m/L}} \quad (\text{mechanical wave on a string})$$

$$P \propto A^2 \quad (\propto \text{ is "proportional to"})$$

$$\frac{I_1}{I_2} = \left( \frac{r_2}{r_1} \right)^2$$

$$\beta = (10 \text{ dB}) \log \left( \frac{I}{I_0} \right)$$

$$\lambda_n = \frac{2L}{n}, f_n = \frac{nv}{2L}, n = 1, 2, 3, \dots \quad (\text{node-node})$$

$$\lambda_n = \frac{4L}{n}, f_n = \frac{nv}{4L}, n = 1, 3, 5, \dots \quad (\text{node-antinode})$$

$$f_{\text{obs}} = \frac{v \pm v_{\text{obs}}}{v \mp v_s} f_s \quad (\text{"top is towards"})$$

- Temperature & Heat:

$$k_B = 1.38 \times 10^{-23} \frac{\text{J}}{\text{K}}$$

$$N_A = 6.02 \times 10^{23} \frac{1}{\text{mol}}$$

$$R = 8.314 \frac{\text{J}}{\text{mol K}}$$

$$\Delta l = l_0 \alpha \Delta T$$

$$PV = Nk_B T = nRT$$

$$Nk_B = nR$$

$$N = nN_A$$

$$K_{av} = \frac{3}{2} k_B T$$

$$v_{\text{rms}} = \sqrt{\frac{3k_B T}{m}}$$

- Thermodynamics:

- Heat Transfer:

$$\sigma = 5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2 \text{K}^4}$$

$$\frac{Q}{\Delta t} = kA \frac{\Delta T}{L} \quad (\text{conduction})$$

$$I = \epsilon \sigma T^4 \quad (\text{radiation})$$

- First Law of Thermodynamics:

$$\Delta U = Q + W$$

$$U = \frac{3}{2} N k_B T$$

$$W = -P\Delta V$$

- Second Law of Thermodynamics:

$$\Delta S_{tot} \geq 0$$

$$\Delta S \geq \frac{Q}{T} \quad (\text{constant } T)$$

- Heat Engines and Refrigerators

$$e = \frac{W}{Q_H}$$

$$e_{\text{Carnot}} = 1 - \frac{T_C}{T_H}$$

$$COP = \frac{Q_C}{W}$$

$$COP_{\text{Carnot}} = \frac{T_C}{T_H - T_C}$$

- Unit Conversions:

$$1 \frac{\text{km}}{\text{hr}} = 0.2778 \frac{\text{m}}{\text{s}}$$

$$1 \text{ rpm} = 0.1047 \frac{\text{rad}}{\text{s}}$$

$$1 \text{ atm} = 1 \times 10^5 \text{ Pa}$$

$$T_K = T_{\circ C} + 273$$

$$T_{\circ F} = \frac{9}{5} T_{\circ C} + 32$$

$$1 \text{ cal} = 4.184 \text{ J}$$