Geometry/Trigonometry:

$$\cos(30°) = \frac{1}{2}\sqrt{3} \quad \sin(30°) = \frac{1}{2} \quad \tan(30°) = \frac{1}{3}\sqrt{3}$$

$$\cos(45°) = \frac{1}{2}\sqrt{2} \quad \sin(45°) = \frac{1}{2}\sqrt{2} \quad \tan(45°) = 1$$

$$\cos(60°) = \frac{1}{2} \quad \sin(60°) = \frac{1}{2}\sqrt{3} \quad \tan(60°) = \sqrt{3}$$

$$\cos\left(\frac{1}{2}\pi - \theta\right) = \sin(\theta) \qquad \sin\left(\frac{1}{2}\pi - \theta\right) = \cos(\theta)$$

$$\cos(2\theta) = 1 - 2\sin^2(\theta) \qquad \sin(2\theta) = 2\sin(\theta)\cos(\theta)$$

	circle	sphere
circumference	$2\pi r$	
(surface) area	πr^2	$4\pi r^2$
volume		$\frac{4}{3}\pi r^3$

Integrating and Differentiating:

$$\frac{d(x^n)}{dx} = nx^{n-1}$$

$$\int x^n dx = \frac{x^{n+1}}{n+1}$$

Linear Motion in One Dimension (general):

$$v = \frac{dx}{dt}$$

$$a = \frac{dv}{dt} = \frac{d^2x}{dt^2}$$

Linear Motion in One Dimension (special case):

$$a(t) = a = \text{ constant}$$

$$v(t) = v_0 + at$$

$$x(t) = x_0 + v_0 t + \frac{1}{2}at^2$$

Linear Motion in Two/Three Dimensions:

$$\vec{v} = \frac{d\vec{r}}{dt}$$

$$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d^2\vec{r}}{dt^2}$$

Circular Motion:

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

$$a_{\tan} = \frac{dv}{dt}$$

Force Laws:

$\sum_i \vec{F}_i = m\vec{a}$ Newton's Second Law of Motion

$\vec{F}_{12} = -\vec{F}_{21}$ Newton's Third Law of Motion

Friction:

$F_s \le \mu_s N$ Static Friction

$F_k = \mu_k N$ Kinetic Friction

$F_D = -bv$ Dragg Force

Newton's Gravitational Law:

$$\vec{F}_{12} = -G\frac{m_1 m_2}{r^2_{21}}\hat{r}_{21}$$

Kepler's Third Law (Law of Periods):

$$\left(\frac{T_1}{T_2}\right)^2 = \left(\frac{r_1}{r_2}\right)^3$$

Work Done by a Force:

$W = \vec{F} \bullet \vec{d}$ Constant Force

$W = \int_a^b \vec{F} \bullet d\vec{l}$ Variable Force

Translation Kinetic Energy:

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

Work-Energy Theorem:

$$W = \Delta K$$

Potential Energy:

$\Delta U = U_2 - U_1 = -\int_1^2 \vec{F} \bullet d\vec{l} = -W$ General Definition of Potential Energy

$$\vec{F} = -\frac{dU}{dx}\hat{x} - \frac{dU}{dy}\hat{y} - \frac{dU}{dz}\hat{z}$$

$U(h) = mgh$ Gravitational Potential Energy (Close to the Surface)

$U(r) = -G\frac{mM_E}{r}$ Gravitational Potential Energy ($r > r_E$)

$U(x) = \frac{1}{2}kx^2$ Spring with Spring Constant k

Conservation of Energy:

$\Delta U + \Delta K = 0$ Conservation of Mechanical Energy

$\Delta U + \Delta K = W_{NC}$ Conservation of Energy

Power:

$$P = \frac{dW}{dt}$$

Linear Momentum and Newton's Second Law:

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

$$\frac{d\vec{p}}{dt} = \sum \vec{F}$$

Collision Impulse:

$$\vec{J} = \int_{t_1}^{t_2} \vec{F} dt = \vec{p}_f - \vec{p}_i = \Delta \vec{p}$$

Elastic Collisions in One Dimension:

$$v_1' = v_1\left(\frac{m_1 - m_2}{m_1 + m_2}\right) + v_2\left(\frac{2m_2}{m_1 + m_2}\right)$$

$$v_2' = v_1\left(\frac{2m_1}{m_1 + m_2}\right) + v_2\left(\frac{m_1 - m_2}{m_1 + m_2}\right)$$

Center of Mass:

$$\vec{r}_{cm} = \frac{\sum_i m_i \vec{r}_i}{\sum_i m_i}$$

$$\vec{r}_{cm} = \frac{1}{M}\int \vec{r} dm$$

Motion of the Center of Mass:

$$M\vec{a}_{cm} = \sum \vec{F}_i$$

Rocket Equations:

$$M\frac{d\vec{v}}{dt} = \sum \vec{F}_{ext} + \vec{v}_{rel}\frac{dM}{dt}$$

$Ma_{rocket} = RU_0$ First Rocket Equation

$v_f = v_i + u\ln\left(\frac{M_i}{M_f}\right)$ Second Rocket Equation

Angular Variables:

	Definition	Linear Variable
Angular Position	θ	$l = R\theta$
Angular Velocity	$\omega = \frac{d\theta}{dt}$	$v = R\omega$
Angular Acceleration	$\alpha_{\tan} = \frac{d^2\theta}{dt^2}$	$a_{\tan} = R\alpha_{\tan}$

Equations of Motion for Constant Acceleration:

	Rotationional Motion	Linear Motion
Acceleration	$\alpha(t) = \alpha$	$a(t) = a$
Velocity	$\omega(t) = \omega_0 + \alpha t$	$v(t) = v_0 + at$
Position	$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$	$x(t) = x_0 + v_0 t + \frac{1}{2}at^2$

Moment of Inertia:

Moment of Inertia: $I = \sum_i m_r r_i^2$ (individual point masses)

$I = \int_{Voume} r^2 dm$ (continuous mass distribution)

Parallel-axis Theorem $I = I_{cm} + Mh^2$

Perpendicular-axis Theorem $I_z = I_x + I_y$

Torque:

Definition: $\bar{\tau} = \bar{r} \times \bar{F}$

Newton's Second Law for Rotational Motion: $\bar{\tau} = I\bar{\alpha}$

Angular Momentum:

Definition: $\bar{L} = \bar{r} \times \bar{p}$

Rotating rigid object: $\bar{L} = I\bar{\omega}$

Relation between torque and angular momentum: $\frac{d\bar{L}}{dt} = \sum \bar{\tau}$

Rotational Energy:

Kinetic energy: $K = \frac{1}{2} I\omega^2$

Work: $W = \int \tau d\theta$

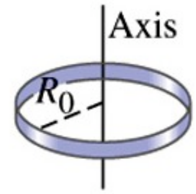
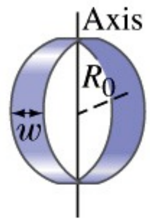
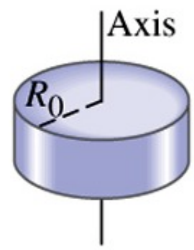
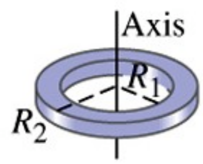
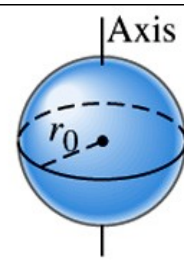
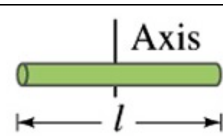
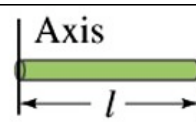
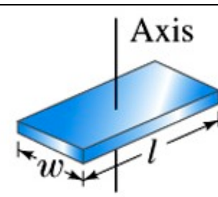
Power: $P = \tau\omega$

Work-Energy Theorem: $W = \Delta K = \frac{1}{2} I\omega_f^{\ 2} - \frac{1}{2} I\omega_i^{\ 2}$

Precession:

$$\Omega = \frac{Mgr_{cm}}{L}$$

Moments of inertia of various objects of uniform composition.

(a)	Thin hoop of radius R_0	Through center		MR_0^2
(b)	Thin hoop of radius R_0 and width w	Through central diameter		$\frac{1}{2}MR_0^2 + \frac{1}{12}Mw^2$
(c)	Solid cylinder of radius R_0	Through center		$\frac{1}{2}MR_0^2$
(d)	Hollow cylinder of inner radius R_1 and outer radius R_2	Through center		$\frac{1}{2}M(R_1^2 + R_2^2)$
(e)	Uniform sphere of radius r_0	Through center		$\frac{2}{5}Mr_0^2$
(f)	Long uniform rod of length l	Through center		$\frac{1}{12}Ml^2$
(g)	Long uniform rod of length l	Through end		$\frac{1}{3}Ml^2$
(h)	Rectangular thin plate, of length l and width w	Through center		$\frac{1}{12}M(l^2 + w^2)$

Conditions for Equilibrium:

$$\sum F_x = 0 \quad \sum \tau_x = 0$$

$$\sum F_y = 0 \quad \sum \tau_y = 0$$

$$\sum F_z = 0 \quad \sum \tau_z = 0$$

Hooke's Law:

$$F = k\Delta L$$

Stress:

stress = force/area = F/A

Strain:

strain = change in length / original length = $\Delta L/L_0$

Young's Modulus *E*:

E = stress/strain

Simple Harmonic Motion:

Definition:	$x(t) = A\cos(\omega t + \phi)$
	A = Amplitude
	ω = angular frequency
	ϕ = phase
Force Requirement:	$F(x) = -m\omega^2 x$
Period:	$T = 2\pi / \omega$
Frequency:	$f = 1/T = \omega / 2\pi$

The Physical Pendulum:

$$T = 2\pi\sqrt{\frac{I}{mgh}}$$

Damped Harmonic Motion (damping force = -*bv*):

Solution: $x(t) = Ae^{-\alpha t}\cos(\omega t)$

A = Amplitude

$$\omega = \sqrt{\frac{k}{m} - \frac{b^2}{4m^2}}$$

$$\alpha = \frac{b}{2m}$$

Forced Harmonic Motion (external force $F_{ext} = F_0 \cos(\omega t)$ and damping force = -*bv*):

Solution: $x(t) = A_0 \cos(\omega t + \phi_0)$

$$A_0 = \frac{F_0}{m\sqrt{\left(\omega^2 - \omega_0{}^2\right)^2 + \frac{b^2\omega^2}{m^2}}}$$

$$\phi_0 = \tan^{-1}\left(\frac{\omega_0{}^2 - \omega^2}{\omega\left(\frac{b}{m}\right)}\right)$$

$$\omega_0 = \sqrt{\frac{k}{m}}$$

Thermal Expansion:

$\Delta L = \alpha L_0 \Delta T$ Linear Expansion

$\Delta V = \beta V_0 \Delta T$ Volume Expansion

$\beta \approx 3\alpha$

Ideal Gas Law:

$PV = nRT$

$PV = NkT$

Average Translational Kinetic Energy for an Ideal Gas:

$$\bar{K} = \frac{3}{2}kT$$

The Maxwell Distribution:

$$f(v) = 4\pi N\left(\frac{m}{2\pi kT}\right)^{\frac{3}{2}} v^2 e^{-\frac{1}{2}\frac{mv^2}{kT}}$$

Mean free path in a gas:

$$l_M = \frac{1}{4\pi r^2 (N/V)}$$

Specific Heat *c*:

$$Q = mc\Delta T$$

Molar Specific Heats for Gases:

$Q = nC_V\Delta T$ Constant Volume

$Q = nC_P\Delta T$ Constant Pressure

$$C_P - C_V = R$$

$C_V = \frac{3}{2}R$ Ideal Monatomic Gas

Latent Heat *L*:

$$Q = mL$$

First Law of Thermodynamics:

$$\Delta U = Q - W$$

Adiabatic Expansion of a Gas:

$$PV^\gamma = \text{constant}$$

Work Done during Volume Changes of an Ideal Gas:

$$W = nRT \ln \frac{V_B}{V_A}$$ Isothermal Process

$$W = nRT_B \left(1 - \frac{V_A}{V_B} \right)$$ Isobaric Process

Heat Transfer:

$$\frac{\Delta Q}{\Delta t} = kA \frac{T_1 - T_2}{l}$$

Efficiency of a Heat Engine:

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

Coefficient of Performance of Refrigerators and Air Conditioners:

$$CP = \frac{|Q_L|}{|W|}$$

Coefficient of Performance of Heat Pumps:

$$CP = \frac{|Q_H|}{|W|}$$

Carnot Efficiency:

$$e = 1 - \frac{T_L}{T_H}$$

Entropy:

$$dS = \frac{dQ}{T}$$