$x = x_0 + \int_{t_0}^{t} v_x dt$ $v_x = \frac{dx}{dt}$ $v_{x,avg} = \frac{\Delta x}{\Delta t}$ $\theta = \theta_0 + \int_{t_0}^{t} \omega\, dt$ $\omega = \frac{d\theta}{dt}$ $\omega_{avg} = \frac{\Delta\theta}{\Delta t}$

$v_x = v_{x0} + \int_{t_0}^{t} a_x dt$ $a_x = \frac{dv_x}{dt}$ $a_{x,avg} = \frac{\Delta v_x}{\Delta t}$ $\omega = \omega_0 + \int_{t_0}^{t} \alpha\, dt$ $\alpha = \frac{d\omega}{dt}$ $\alpha_{avg} = \frac{\Delta\omega}{\Delta t}$

$v_x = v_{x0} + a_x \Delta t$

$x = x_0 + v_{x0}\Delta t + \frac{1}{2} a_x (\Delta t)^2$

$v_x{}^2 = v_{x0}{}^2 + 2a_x \Delta x$

Similar equations apply for motion along *y* and *z*.

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

$\theta = \theta_0 + \omega_0 \Delta t + \frac{1}{2}\alpha\, (\Delta t)^2$

$\omega^2 = \omega_0{}^2 + 2\alpha\, \Delta\theta$

$a_{rad} = v^2 / R = \omega^2 R$ $a_{tan} = \alpha R$ $v_{tan} = \omega R$ $s = \theta R$

$\vec{F}_{net} = m\vec{a}$ $\vec{\tau}_{net} = I\vec{\alpha}$

$w = mg$ OR $F_g = G m_1 m_2 / r^2$ $\vec{F}_{spring} = -k(\Delta\vec{x})$ $\vec{\tau} = \vec{r} \times \vec{F}$

$f_s \le \mu_s n$ $f_k = \mu_k n$ $f_r = \mu_r n$ where $|\tau| = lF = rF \sin\phi = rF_{\tan}$

$f_{drag} = kv$ (low speed) OR $f_{drag} = Dv^2$ (high speed) $I = \sum_i m_i r_i^2$

$\Delta K = W_{total}$ $W_c = -\Delta U$ $W_{NC} = -\Delta U_{\text{int}} = \Delta E$ where $E = K + U$

$\Delta K + \Delta U + \Delta U_{\text{int}} = 0$ $K_i + U_i + W_{NC} = K_f + U_f$

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

$W = \int_{s_i}^{s_f} \vec{F} \bullet d\vec{s}$ $P = \frac{dW}{dt} = \vec{F} \bullet \vec{v}$ $W = \int_{\theta_i}^{\theta_f} \tau_z\, d\theta$ $P = \frac{dW}{dt} = \tau_z \omega_z$

$U_g = mgy$ OR $U_g = -G m_1 m_2 / r$ $U_{elastic} = \frac{1}{2} k (\Delta x)^2$ $F_x(x) = \frac{-dU(x)}{dx}$

$\vec{p} = m\vec{v}$ $\vec{L} = \vec{r} \times \vec{p} = \vec{r} \times m\vec{v} = I\vec{\omega}$

$\vec{F}_{net} = \frac{d\vec{p}}{dt}$ $\vec{J} = \int_{t_i}^{t_f} \vec{F}_{net}\, dt = \Delta\vec{p}$ $\vec{\tau}_{net} = \frac{d\vec{L}}{dt}$

Iω applies only for a rigid body around an axis of symmetry

$p = p_0 + \rho g h$ $F_B = m_{fl,disp}\, g = \rho_{fl} V_{fl,disp}\, g$ $\frac{dV}{dt} = Av = \text{constant}$ $p + \rho g y + \frac{1}{2}\rho v^2 = \text{constant}$

Simple harmonic oscillator: $x(t) = A\cos(\omega t + \phi_0)$

$\omega = 2\pi f = 2\pi / T$ where $\omega = \sqrt{k/m}$ (spring-mass) OR $\omega = \sqrt{\kappa / I}$ (torsion spring)

OR $\omega = \sqrt{g/L}$ (simple pendulum) OR $\omega = \sqrt{mgd/I}$ (physical pendulum)

Slightly damped oscillator: $x(t) = Ae^{-(0.5b/m)t} \cos(\omega' t + \phi_0)$ where $\omega' = \sqrt{\frac{k}{m} - \frac{b^2}{4m^2}}$

$y(x,t) = A\cos\left[2\pi\left(\frac{x \mp vt}{\lambda}\right)\right] = A\cos\left[2\pi\left(\frac{x}{\lambda} \mp \frac{t}{T}\right)\right] = A\cos(kx \mp \omega t)$ where $k = 2\pi/\lambda$ and $v = \lambda / T = \lambda f$

transverse, string/spring: $v = \sqrt{T/\mu}$ $P_{avg} = \frac{1}{2}\omega^2 A^2 \sqrt{\mu T}$

longitudinal, fluid or bulk solid: $v = \sqrt{B/\rho}$ $I = \frac{1}{2}\omega^2 A^2 \sqrt{\rho B} = p_{\max}^2 / (2\rho v)$ where $p_{\max} = 2\pi B A / \lambda$

$I_1 / I_2 = r_2^2 / r_1^2$ $\beta = (10\ \text{dB}) \log(I / I_0)$

$y(x,t) = A_{SW} \sin(kx + \phi_0) \sin(\omega t)$ where $A_{SW} = 2A$ (standing wave)

$f_n = n\frac{v}{2L} = n f_1$ $\lambda_n = 2L/n$ where n = 1,2,3,… (string or open pipe)

$f_n = n\frac{v}{4L} = n f_1$ $\lambda_n = 4L/n$ where n = 1,3,5,… (stopped pipe)

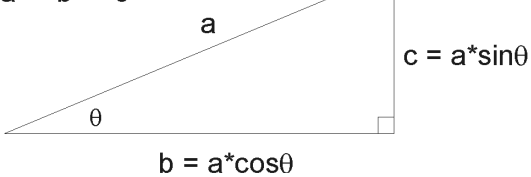
Useful Constants

$g = 9.8$ m/s^2
$G = 6.673 \times 10^{-11}$ N m^2 / kg^2
$I_0 = 1.0 \times 10^{-12}$ W / m^2
$p_{atm} = 1.013 \times 10^5$ Pa = 1 atm

Algebra and trigonometry

$$ax^2 + bx + c = 0 \quad \Rightarrow \quad x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$a^2 = b^2 + c^2$



Moments of Inertia

slender rod (length L), through center	$I = \frac{1}{12} ML^2$
slender rod (length L), through end	$I = \frac{1}{3} ML^2$
rectangular plate (a by b), through center	$I = \frac{1}{12} M(a^2 + b^2)$
rectangular plate (a by b), along edge b	$I = \frac{1}{3} Ma^2$
hollow cylinder (inner radius R_1, outer R_2)	$I = \frac{1}{2} M\left(R_1^2 + R_2^2\right)$
solid cylinder, (radius R)	$I = \frac{1}{2} MR^2$
thin-walled hollow cylinder, (radius R)	$I = MR^2$
solid sphere (radius R)	$I = \frac{2}{5} MR^2$
thin-walled hollow sphere (radius R)	$I = \frac{2}{3} MR^2$

Astronomical Data

	Mass (kg)	Radius (m)	Orbit radius (m)	Orbit period
Sun	1.99×10^{30}	6.96×10^{8}	------	-----
Moon	7.35×10^{22}	1.74×10^{6}	3.84×10^{8}	27.3 days
Mercury	3.30×10^{23}	2.44×10^{6}	5.79×10^{10}	88.0 days
Venus	4.87×10^{24}	6.05×10^{6}	1.08×10^{11}	224.7 days
Earth	5.97×10^{24}	6.38×10^{6}	1.50×10^{11}	365.3 days
Mars	6.42×10^{23}	3.40×10^{6}	2.28×10^{11}	687.0 days
Jupiter	1.90×10^{27}	6.91×10^{7}	7.78×10^{11}	11.86 yrs
Saturn	5.68×10^{26}	6.03×10^{7}	1.43×10^{12}	29.45 yrs
Uranus	8.68×10^{25}	2.56×10^{7}	2.87×10^{12}	84.02 yrs
Neptune	1.02×10^{26}	2.48×10^{7}	4.50×10^{12}	164.8 yrs
Pluto	1.31×10^{22}	1.15×10^{6}	5.91×10^{12}	247.9 yrs

*** For each body, "radius" is its radius at the equator and "orbit radius" is its average distance from the sun (for the planets) or from the earth (for the moon).