Eq.: $g = 9.8\ m/s^2$, $1\ mm = 10^{-3}\ m$, $1\ cm = 10^{-2}\ m$, $1\ km = 10^3\ m$, $1\ in = 2.54\ cm$, $1\ mi = 1609\ m$; $1\ N\ (newton) = kg\ \cdot m/s^2$, $1\ J\ (joule) = N\ \cdot m = kg\ \cdot m^2/s^2$, $1\ W\ (watt) = J/s$, density $= \text{mass/volume}$.

Volumes. Cylinder: $\pi R^2 h$, sphere: $\frac{4}{3}\pi R^3$, cone: $\frac{1}{3}\pi R^2 h$

Quadratic equation. $ax^2 + bx + c = 0$, $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

Derivatives/integrals. $\frac{d}{dt} r^n = n t^{n-1}$, $\int r^n \, dr = \frac{1}{n+1} r^{n+1}$

Vectors. If $\vec{c} = \vec{a} + \vec{b}$, then $c_x = a_x + b_x$, $c_y = a_y + b_y$, $c_z = a_z + b_z$ and $c = \sqrt{c_x^2 + c_y^2 + c_z^2}$.

Dot product: $\vec{a} \cdot \vec{b} = a_x b_x + a_y b_y + a_z b_z = ab \cos \alpha$. Cross product: $|\vec{A} \times \vec{B}| = A B \sin \alpha$, $\hat{i} \times \hat{j} = \hat{k}$, $\hat{j} \times \hat{i} = \hat{k}$.

Kinematics. $v = dx/dt$, $a = dv/dt = d^2x/dt^2$. Constant $a$: $v - v_0 = at$, $x - x_0 = \frac{v_0 + v}{2} t = v_0 t + \frac{1}{2} a t^2 = \frac{v^2 - v_0^2}{2a}$. Projectile: $v_x = \text{const}$, $x - x_0 = v_x t$, $v_y = v_0_y - gt$, $y - y_0 = v_0_y t - \frac{1}{2} gt^2 = (v_0^y - v_y^2)/(2g)$. Range: $(v_0^y/g) \sin(2\theta)$.

Circular motion with constant speed: $\omega = v/R$, $a_c = v^2/R = \omega^2 R$, towards center.

The three Laws of motion: (1) If $\vec{F}_{net} = 0$ then $\vec{v} = \text{const}$; (2) $\vec{F}_{net} = m\vec{a}$; (3) $\vec{F}_{21} = -\vec{F}_{12}$

Specific forces. Gravity: $m\vec{g}$ (down). Normal $\vec{N}$ - perpendicular to surface; tension $T$ - constant along the string. Spring force: $F = -kx$ (k is spring constant).

Friction - parallel to surface: kinetic: $f_k = \mu_k N$; static: $f_s \leq \mu_s N$ with $N = mg$ (horizontal plane) or $N = mg\cos\theta$ (inclined plane).

Inclined plane. Components of gravity: $mg\sin\theta$ (parallel to plane, downhill) and $mg\cos\theta$ (perpendicular to plane). Kinetic friction: $\mu_k mg \cos \theta$ (parallel to plane, opposite to direction of motion).

Centripetal motion: $F_{net} = m v^2/R$; direction of $\vec{F}_{net}$ - towards center of revolution.

Work and power. Constant force $W = \vec{F} \cdot (\vec{r}_2 - \vec{r}_1) = F_x \Delta x + F_y \Delta y + F_z \Delta z$ (or, $W = F \Delta x \cos \alpha$); general: $W_{AB} = \int_A^B \vec{F} \cdot d\vec{r}$. Power: $P = W/\Delta t = \vec{F} \cdot \vec{v}$. Work by specific forces: gravity: $W_g = -mg \Delta y$ (and $\Delta x$ does not matter); normal: $W_N = 0$; kinetic friction: $W_f = -f L$; spring $W_s = \frac{1}{2} k (x_1^2 - x_2^2)$

Kinetic energy and work-energy theorem: $K = \frac{1}{2} m v^2$, $\Delta K = W$ where $W$ is the net work (i.e. work by all forces).

Potential energy. For conservative forces (with path-independent work) introduce $U(\vec{r})$ so that $W_{AB} = U_A - U_B = -\Delta U$. For specific forces: gravity: $U_g = mgh$; spring: $U_s = \frac{1}{2} k x^2$. If only conservative forces, then energy conservation: $\Delta K + \Delta U = 0$ or $K + U = \text{const}$. If also non-conservative forces (e.g., friction) with $W_{non-cons}$, then $\Delta (K + U) = W_{non-cons}$

Momentum. $\vec{p} = m\vec{v}$, $\vec{P}_{tot} = \sum m_i \vec{v}_i$. Impulse $\Delta \vec{p} = \vec{F}_{ext} \Delta t$. Conservation: if $\vec{F}_{ext} = 0$, then $\vec{P}_{tot} = \text{const}$ (e.g., in collisions). Center-of-mass: $\vec{R}_{cm} = \frac{1}{M} \sum m_i \vec{r}_i$, $M = \sum M_i$; $\vec{P} = M \vec{V}_{cm}$

Rotation (kinematics): If $N$-number of revolutions, then $\theta = 2\pi N$. Angular velocity $\omega = d\theta/dt$ (in rad/s); ang. acceleration $\alpha = d\omega/dt$ (in rad/s^2). If $\alpha = \text{const}$, then $\theta = \frac{\omega^2 - \omega_0^2}{2\alpha} t$; or $\theta = \omega_0 t + \frac{1}{2}\alpha t^2$, and $\omega = \omega_0 + \alpha t$. Connection with linear: $\omega = v/r$, $\alpha = a/r$

Dynamics: $K = \frac{1}{2} I \omega^2$; I-moment of inertia. For point masses: $I = \sum m_i r_i^2$, for solid bodies $I = \int dV \rho r^2$. Specific $I$’s: rod (about center) $ML^2/12$; rod (about end) $ML^2/3$; hoop $MR^2$; disk $MR^2/2$; solid sphere $2/5 MR^2$; spherical shell $2/3 MR^2$. Parallel axes theorem: $I = I_{CM} + MD^2$

Rotation+linear: $K = \frac{1}{2} m v^2 + \frac{1}{2} I \omega^2$. If $\omega = v/R$ (e.g., rolling) $K = \frac{1}{2} m v^2 (1 + 1/(mR^2))$
Torque $\vec{\tau} = \vec{r} \times \vec{F}$, $\tau = FR \sin \phi = Fd$. The 2nd Law for rotation: $\tau = I\alpha$.

Angular momentum. $\vec{L} = \sum \vec{r}_i \times \vec{p}_i$ (point masses); $L = I\omega$ (symmetric solid). Conservation: if $\vec{\tau} = 0$ then $\vec{L} = \text{const}$.

**Static equilibrium.** $\sum \vec{F}_i = 0$, $\sum \vec{\tau}_i = 0$.

**Fluids. Statics.** $P = F_n/A$, $P = \rho gh$ (barostatic equation), $F_B = \rho_{\text{fluid}} g V_{\text{submerged}}$ (Archimedes Law).

**Fluids. Dynamics.** Continuity equation: $\rho v A = \text{const}$. For incompressible fluid $v * A = \text{const}$.

Bernoulli equation: $P + \rho gh + \frac{1}{2} \rho v^2 = \text{const}$.

**Gravity.** $F = -GMm/r^2$, $g(r) = -GM/r^2$. $U(r) = -GMm/r$. 3rd Law of Kepler: $T^2 \propto r^3$, $T = (2\pi/\sqrt{GM}) r^{3/2}$. Satellite: $v_{\text{orb}} = \sqrt{g(r) * r}$, $r$-distance from center of planet (for low orbits $r \approx R_p$); $g(r) = g_s * (R_p/r)^2$. Escape: $v_{\text{esc}} = \sqrt{2v_{\text{orb}}} = \sqrt{2GM_p/R_p}$ (from surface of planet). $G = 6.67 \times 10^{-11} \text{N} \cdot \text{m}^2/\text{kg}^2$. $M_{\text{sun}} = 1.99 \times 10^{30} \text{kg}$; $M_{\text{earth}} = 5.97 \times 10^{24} \text{kg}$; distance from Sun to Earth $150 \times 10^6 \text{km}$; radius of Earth $R_{\text{earth}} \approx 6400 \text{km}$. 
