The momentum principle:

$$d\vec{\mathbf{p}} = \vec{\mathbf{F}}_{net}dt$$

$$\vec{\mathbf{p}} = \frac{m\vec{\mathbf{v}}}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$\vec{\mathbf{p}}_{new} = \vec{\mathbf{p}}_{old} + \vec{\mathbf{F}}_{net}\Delta t$$

$$\vec{\mathbf{r}}_{new} = \vec{\mathbf{r}}_{old} + \frac{1}{\sqrt{1+\left(\frac{p}{mc}\right)^2}}\left(\frac{\vec{\mathbf{p}}}{m}\right)\Delta t$$

Equations of motion in 1D for constant acceleration and low velocities ($v \ll c$):

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

$$v(t) = \frac{dx(t)}{dt} = v_0 + at$$

$$a(t) = \frac{dv(t)}{dt} = a = \text{constant}$$

Requirement for uniform circular motion:

$$F_r = \frac{mv^2}{r}$$

Rotational motion:

$$d = \theta r$$

$$v = \omega r \quad \omega = \frac{d\theta}{dt}$$

$$a = \alpha r \quad \alpha = \frac{d\omega}{dt}$$

Gravitational force:

$$\vec{\mathbf{F}} = G\frac{m_1 m_2}{r^2}\hat{\mathbf{r}}$$

$\vec{\mathbf{F}} = m\vec{\mathbf{g}}$ (close to the surface of the Earth)

Electrostatic force:

$$\vec{\mathbf{F}} = -\frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{\mathbf{r}}$$

Harmonic motion:

$$F = -kx$$

$x(t) = x_{\max}\cos(\omega t + \phi)$ where $\omega = \sqrt{\frac{k}{m}}$

$$T = \frac{2\pi}{\omega}$$

Damped harmonic motion:

$$x(t) = x_m e^{-\frac{bt}{2m}} e^{it\sqrt{\frac{k}{m}}}$$

Driven harmonic motion:

$$x(t) = \frac{F_0}{\omega_0{}^2 - \omega^2}\cos(\omega t + \phi)$$

Stress and strain:

$$\frac{F}{A} = Y\frac{\Delta L}{L}$$

$$Y = \frac{k_s}{d}$$

Work done by a force:

$W = \vec{\mathbf{F}}\bullet\vec{\mathbf{d}}$ constant force

$= \int_{\vec{\mathbf{r}}_1}^{\vec{\mathbf{r}}_2} \vec{\mathbf{F}}\bullet d\vec{\mathbf{r}}$ variable force

Power:

$$P = \frac{dW}{dt} = \vec{\mathbf{F}}\bullet\vec{\mathbf{v}}$$

Work-energy theorem:

$$\Delta E_{system} = W$$

$$E_{system} = \left(E_1 + E_2 + E_3 + ...\right) + U$$

Relativistic energy relations:

$$E = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}} = mc^2 + K$$

$$E^2 - (pc)^2 = \left(mc^2\right)^2$$

$$K = \frac{mc^2}{\sqrt{1 - \frac{v^2}{c^2}}} - mc^2 \underset{v \ll c}{\rightarrow} \frac{1}{2}mv^2$$

Potential energy:

$$\Delta U = -W_{\text{internal}} = -\int \vec{\mathbf{F}} \bullet d\vec{\mathbf{r}}$$

$$\vec{\mathbf{F}} = -\vec{\nabla} U = \begin{pmatrix} -\frac{\partial U}{\partial x} \\ -\frac{\partial U}{\partial y} \\ -\frac{\partial U}{\partial z} \end{pmatrix}$$

$$U_{gravity} = -G\frac{m_1 m_2}{r}$$

$$U_{gravity} = mgh$$

$$U_{electric} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r}$$

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

Heat capacity:

$$\Delta E_{thermal} = mC\Delta T$$

Friction forces:

$$f_s \le \mu_s N$$

$$f_k = \mu_k N$$

Drag force (air):

$$\vec{\mathbf{F}}_{air} = -\frac{1}{2}C\rho A v^2 \hat{\mathbf{v}}$$

Energy levels for the Hydrogen atom:

$$E_N = \frac{-13.6}{N^2}\ \text{eV},\ N = 1,2,3,...$$

Vibrational energy levels:

$$E_N = E_0 + N\hbar\omega_0 = E_0 + N\hbar\sqrt{\frac{k_s}{m}},\ N = 0,1,2,..$$

Energy and wavelength of light:

$$E_{photon} = \frac{hc}{\lambda_{light}}$$

Center of mass:

$$\vec{\mathbf{r}}_{cm} = \frac{\sum_i m_i \vec{\mathbf{r}}_i}{\sum_i m_i} = \frac{1}{M}\sum_i m_i \vec{\mathbf{r}}_i$$

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

Motion of the center of mass:

$$M\vec{\mathbf{a}}_{cm} = \vec{\mathbf{F}}_{net,ext}$$

Gravitational potential energy of a multi-particle system:

$$U = Mgy_{cm}$$

Kinetic energy of a multi-particle system:

$$K = K_{trans} + K_{rel} = \frac{1}{2} M v_{cm}{}^{2} + K_{rel}$$

Impulse of a force:

$$\vec{\mathbf{J}} = \int \vec{\mathbf{F}} dt$$

Momentum and impulse:

$$\vec{\mathbf{J}} = \vec{\mathbf{p}}_f - \vec{\mathbf{p}}_i$$

Conservation of linear momentum:

$$\Delta\vec{\mathbf{P}}_{system} + \Delta\vec{\mathbf{P}}_{surroundings} = 0$$

Elastic collision in one dimension (mass 2 at rest before the collision):

$$v_{1f} = \frac{m_1 - m_2}{m_1 + m_2} v_{1i}$$

$$v_{2f} = \frac{2m_1}{m_1 + m_2} v_{1i}$$

Completely inelastic collision in one dimension (mass 2 at rest before the collision):

$$v_f = \frac{m_1}{m_1 + m_2} v_i$$

Moment of inertia:

$$I = \sum_i m_i r_i^2 \quad \text{Discreet mass distribution}$$

$$I = \int_{Volume} r^2 dm \quad \text{Continuous mass distribution}$$

Kinetic energy of a rotating rigid object:

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

Torque:

$$\vec{\tau} = \vec{\mathbf{r}} \times \vec{\mathbf{F}}$$

Newton's "second" law for rotational motion:

$$\vec{\tau} = I\vec{\alpha}$$

Angular momentum of a single particle:

$$\vec{\mathbf{L}} = \vec{\mathbf{r}} \times \vec{\mathbf{p}}$$

Angular momentum of a rotating rigid object:

$$\vec{\mathbf{L}} = I\vec{\omega}$$

The angular momentum principle:

$$\frac{d\vec{\mathbf{L}}}{dt} = \left(\vec{\mathbf{r}} \times \vec{\mathbf{F}}\right)_{\text{net, ext}} = \vec{\tau}_{\text{net, ext}}$$

Number of micro states:

$$\Omega = \frac{(q + N - 1)!}{q!(N-1)!}$$

Definition of entropy S:

$$S = k \ln \Omega$$

Definition of temperature T:

$$\frac{1}{T} = \frac{dS}{dE_{\text{int}}}$$

The Boltzmann distribution:

$$P(\Delta E) \propto e^{-\Delta E/kT}$$

The Maxwell-Boltzmann velocity distribution:

$$P(v) = 4\pi \left(\frac{M}{2\pi kT}\right)^{\frac{3}{2}} v^2 e^{-\frac{1}{2}Mv^2/(kT)}$$

Root-mean-square speed:

$$v_{rms} = \sqrt{\overline{v^2}} = \sqrt{\frac{3kT}{M}}$$

Average translational kinetic energy of an ideal gas:

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

Mean-free path d:

$$\frac{N}{V}\left[\pi\left(R+r\right)^2 d\right] \approx 1$$

Number of gas molecules hitting an area A per second:

$$\text{molecules/s} = \frac{1}{4}\frac{N}{V}A\overline{v}$$

Ideal gas law:

$$pV = NkT$$

Work done by a gas:

$$W = \int_{V_1}^{V_2} p\,dV$$

First law of thermodynamics:

$$\Delta E_{system} = W + Q$$

Isothermal compression:

$$W = NkT\ln\left(\frac{V_1}{V_2}\right)$$

Adiabatic compressions:

$$pV^{\gamma} = pV^{C_p/C_V} = \text{constant}$$

Heat capacity C defined:

$$\Delta Q = C\Delta T$$

Heat capacities per molecule for ideal gasses:

$$C_V = \frac{3}{2}k \qquad \text{monatomic gas}$$

$$C_V \geq \frac{3}{2}k \qquad \text{other gases}$$

$$C_p = C_V + k$$

Rate of thermal energy transfer:

$$\frac{dQ}{dt} = \sigma A\frac{T_H - T_L}{L}$$

Efficiency of a heat engine:

$$\text{efficiency} = \frac{|W|}{Q_H} = 1 - \frac{T_L}{T_H}$$

Quality factor of a heat pump:

$$K = \frac{|Q_C|}{|W|}$$