Newton’s three laws
1) the concept of equilibrium: things at rest stay at rest unless an external force is applied.
2) $F = ma$
3) every action has an equal and opposite reaction

Linear motion:
Galileo’s equations of motion for uniform acceleration
$\mathbf{v} = \mathbf{v}_0 + at$
$x = x_0 + \mathbf{v}_0 t + \frac{1}{2} at^2$
$v^2 = v_0^2 + 2a (x - x_0)$

Forces
$\sum \mathbf{F} = \mathbf{F}_{net} = m \mathbf{a}$
$\mathbf{F} = \frac{d\mathbf{p}}{dt}$

Special case: Friction. Recall that there is the coefficient of static friction and the coefficient of kinetic friction (coeff. static friction is typically the larger of the two)
$F_{fric} \leq \mu N$

Impulse
$\mathbf{J} = \int \mathbf{F} \, dt = \Delta \mathbf{p}$

Momentum and energy ($\mathbf{p}$ conserved always; KE conserved for elastic collisions only)
$\mathbf{p} = m \mathbf{v}$
$K = \frac{1}{2} m \mathbf{v}^2 \quad \Delta U_g = mgh$

Work and Power
$W = \int \mathbf{F} \cdot d\mathbf{r}$
$P = \frac{dW}{dt}$
$P = \mathbf{F} \cdot \mathbf{v}$

Rotations
Angular velocity
$\mathbf{\omega} = \mathbf{r} \times \mathbf{\omega}$
Moment of inertia
Principle axes: the axes around which the object can rotate with constant speed, without the need for any torque.
Parallel Axis Theorem (MoI around a new, parallel axis a distance \( R \) away from the CM of the object)
\[ I_{\text{new}} = MR^2 + I^{CM} \]
Angular Momentum
\[ \vec{L} = MR \times \vec{V} + \sum m_i r_i^2 \]
Kinetic Energy
\[ T = \frac{1}{2} MV^2 + \frac{1}{2} I^{CM} \omega^2 \]
Torque
\[ \tau = \vec{r} \times \vec{F} \]
\[ \sum \tau = \tau_{\text{net}} = I \alpha \]
\[ \vec{r} = \frac{d\vec{L}}{dt} \]
Galileo’s equations of motion for rotation
\[ \vec{\omega} = \vec{\omega}_0 + \alpha t \]
\[ \theta = \theta_0 + \vec{\omega}_0 t + \frac{1}{2} \alpha t^2 \]
Special cases:
Uniform circular motion:
\[ \alpha_c = \frac{v^2}{r} = \omega^2 r \]
Rolling without slipping: this motion can be considered a linear combination of pure translational and pure rotational motion:
Harmonic motion
Force and energy
\[ F_s = -kx \]
\[ U_s = \frac{1}{2} kx^2 \]

Period
\[ T = \frac{2\pi}{\omega} = \frac{1}{f} \]

Period of a mass \((m)\) on a spring \((k)\)
\[ T_s = 2\pi \sqrt{\frac{m}{k}} \]

Period of a pendulum of length \(l\) in the Earth's gravity.
\[ T_p = 2\pi \sqrt{\frac{l}{g}} \]

underdamped, overdamped, and critically damped motion

Gravity, force and potential
\[ F_G = -\frac{Gm_1m_2}{r^2} \hat{i} \]
\[ U_G = -\frac{Gm_1m_2}{r} \]

Central Forces
The effective potential. Note: the first term in the effective potential is the angular momentum barrier that prevents the particle from approaching the source of the gravitational field.
\[ V_{\text{eff}} = \frac{L^2}{2mr^2} + V(r) \]
\[ \frac{1}{2} m\dot{r}^2 + V_{\text{eff}} = E \]

Kepler's 2\textsuperscript{nd} and 3\textsuperscript{rd} Laws
\[ \frac{dA}{dt} = \frac{1}{2} r^2 \dot{\theta} = \text{const} \]
\[ \tau = \frac{A}{dA} = 2\pi \sqrt{\frac{m}{k}} a^{3/2} \]

Coriolis Effect
\[ F_{\text{coriolis}} = -2m(\ddot{\omega} \times \vec{v}_{\text{radial}}) \]

Fluid mechanics:
Pressure on a system due to the fluid above

\[ p = p_0 + \rho gh \]

Force of buoyancy; \( \rho \) is the mass density of the fluid, \( V \) is the volume of fluid displaced.

\[ F_{\text{buoy}} = \rho Vg \]

Motion of a fluid in a tube. \( A_1 \) and \( A_2 \) are the cross-sectional areas at two places in the tube; \( v_1 \) and \( v_2 \) are the speeds of the fluid at those places.

\[ A_1 v_1 = A_2 v_2 \]