**Motion in 1-dimension:**

Displacement $\Delta x = x_f - x_i$

Average velocity $v_{\text{av}} = \dfrac{\Delta x}{\Delta t}$ Instantaneous velocity $v = \lim\limits_{\Delta t \to 0} \dfrac{\Delta x}{\Delta t}$

Average acceleration $a_{\text{av}} = \dfrac{\Delta v}{\Delta t}$ Instantaneous acceleration $a = \lim\limits_{\Delta t \to 0} \dfrac{\Delta v}{\Delta t}$

Motion with constant acceleration:

$$v = v_0 + at \qquad v_{\text{av}} = \tfrac{1}{2}(v_0 + v) \qquad x = x_0 + \tfrac{1}{2}(v_0 + v)t$$

$$x = x_0 + v_0 t + \tfrac{1}{2}at^2 \qquad v^2 = v_0^2 + 2a(x - x_0)$$

Freely falling objects:

Fall with constant acceleration $g$ = 9.81 m/s$^2$ in the downward direction

**Components of a Vector:**

$x$-component of vector $\vec{\boldsymbol{A}}$ $A_x = A\cos\theta$ $\theta$ measured relative to the $x$-axis

$y$-component of vector $\vec{\boldsymbol{A}}$ $A_y = A\sin\theta$ $\theta$ measured relative to the $x$-axis

Note: the components are positive if they point in the positive direction of the coordinate system.

Magnitude of a vector $\vec{\boldsymbol{A}}$ $A = \sqrt{A_x^2 + A_y^2}$

Direction of a vector $\vec{\boldsymbol{A}}$ $\theta = \tan^{-1}(A_y / A_x)$ $\theta$ measured relative to the $x$-axis

Unit vectors $\hat{\boldsymbol{x}}$ vector of length one in the positive $x$ direction

$\hat{\boldsymbol{y}}$ vector of length one in the positive $y$ direction

Vector addition $\vec{\boldsymbol{A}} + \vec{\boldsymbol{B}} = (A_x + B_x)\hat{\boldsymbol{x}} + (A_y + B_y)\hat{\boldsymbol{y}}$

**Motion in 2-dimensions:**

Displacement $\Delta\vec{\boldsymbol{r}} = \vec{\boldsymbol{r}}_f - \vec{\boldsymbol{r}}_i$

Average velocity $\vec{\boldsymbol{v}}_{\text{av}} = \dfrac{\Delta\vec{\boldsymbol{r}}}{\Delta t}$ Instantaneous velocity $\vec{\boldsymbol{v}} = \lim\limits_{\Delta t \to 0} \dfrac{\Delta\vec{\boldsymbol{r}}}{\Delta t}$

Average acceleration $\vec{\boldsymbol{a}}_{\text{av}} = \dfrac{\Delta\vec{\boldsymbol{v}}}{\Delta t}$ Instantaneous acceleration $\vec{\boldsymbol{a}} = \lim\limits_{\Delta t \to 0} \dfrac{\Delta\vec{\boldsymbol{v}}}{\Delta t}$

Motion with constant acceleration:

The motion can be analyzed in terms of the $x$ and $y$ components and the same equations as in the one-dimensional case apply. We specialize to projectile motion where the acceleration is that of gravity alone. That is, with the usual directions of positive $x$ and $y$, the acceleration of the object has components:

$$a_x = 0 \qquad a_y = -g = -9.81 \text{ m/s}^2$$

The equations of motion are then:

$$x = x_0 + v_{0x}t \qquad v_x = v_{0x}$$

$$y = y_0 + v_{0y}t - \tfrac{1}{2}gt^2 \qquad v_y = v_{0y} - gt \qquad v_y^2 = v_{0y}^2 - 2g(y - y_0)$$

For zero launch angle projectile, landing site is $x = v_0\sqrt{\dfrac{2h}{g}}$

For general projectile: Range $R = \left(\dfrac{v_0^2}{g}\right)\sin 2\theta$; Maximum height $y_{\max} = \dfrac{v_0^2 \sin^2\theta}{2g}$

## Chapter 5: Newton's Laws of Motion

Newton's Second Law: $\sum \vec{\boldsymbol{F}} = m\vec{\boldsymbol{a}}$

In component form: $\sum F_x = ma_x$ $\sum F_y = ma_y$ $\sum F_z = ma_z$

## Chapter 6: Applications of Newton's Laws

Kinetic Friction: $f_k = \mu_k N$ $N$ is the normal force

Static Friction: $f_s \le \mu_s N$

Springs – Hooke's Law: $\vec{\boldsymbol{F}} = -k\vec{\boldsymbol{x}}$ Force by spring is opposite to displacement

Circular Motion – Centripetal Acceleration: $a_{\text{cp}} = \dfrac{v^2}{r}$ Direction is towards the center of the circle

## Chapter 7: Work and Kinetic Energy

Work done by Constant Force: $W = Fd\cos\theta$

Kinetic Energy defined: $K = \dfrac{1}{2}mv^2$

Work-Energy Theorem: $W_{\text{total}} = \Delta K = K_f - K_i$

Work done against Spring Force: $W = \dfrac{1}{2}kx^2$

Power – rate of doing work: $P = \dfrac{W}{t} \equiv Fv$

## Chapter 8: Potential Energy and Conservative Forces

Potential Energy $U$: $W_c = -\Delta U = U_i - U_f$ $W_{\text{c}}$ is the work done by a conservative force

Gravitational Potential Energy: $U_{\text{g}} = mgy$

Spring Potential Energy: $U_{\text{s}} = \dfrac{1}{2}kx^2$

Mechanical Energy: $E = U + K$

Total work: $W_{\text{total}} = W_{\text{c}} + W_{\text{nc}}$ $W_{\text{nc}}$ is the work done by all nonconservative forces

$W_{\text{c}}$ is the work done by all conservative forces

Work-Energy Theorem: $W_{\text{nc}} = \Delta E = E_f - E_i$

Conservation of Mechanical Energy: $K_i + U_i = K_f + U_f$ when $W_{\text{nc}} = 0$

## Chapter 9: Linear Momentum and Collisions

Linear Momentum for a single object defined: $\vec{\boldsymbol{p}} = m\vec{\boldsymbol{v}}$

For a system of objects, total momentum is: $\vec{\boldsymbol{p}}_{\text{total}} = \vec{\boldsymbol{p}}_1 + \vec{\boldsymbol{p}}_2 + \vec{\boldsymbol{p}}_3 + \ldots$

Newton's second law: $\sum \vec{\boldsymbol{F}} = \dfrac{\Delta \vec{\boldsymbol{p}}}{\Delta t}$

Impulse of a force: $\vec{\boldsymbol{I}} = \vec{\boldsymbol{F}}_{\text{av}} \Delta t = \Delta \vec{\boldsymbol{p}}$

## Chapter 10: Rotational Kinematics and Energy

Average angular velocity: $\omega_{\text{av}} = \dfrac{\Delta \theta}{\Delta t}$ Instantaneous angular velocity: $\omega = \lim\limits_{\Delta t \to 0} \dfrac{\Delta \theta}{\Delta t}$

Period for uniform rotation: $T = \dfrac{2\pi}{\omega}$

Average angular acceleration: $\alpha_{\text{av}} = \dfrac{\Delta \omega}{\Delta t}$ Instantaneous angular acceleration: $\alpha = \lim\limits_{\Delta t \to 0} \dfrac{\Delta \omega}{\Delta t}$

Rotational kinematic equations: $\omega = \omega_0 + \alpha t$ $\theta = \theta_0 + \tfrac{1}{2}\left(\omega + \omega_0\right)t$

$\theta = \theta_0 + \omega_0 t + \tfrac{1}{2}\alpha t^2$ $\omega^2 = \omega_0^2 + 2\alpha\left(\theta - \theta_0\right)$

Tangential Speed: $v_{\text{t}} = r\omega$ Centripetal acceleration: $a_{\text{cp}} = v^2 / r = r\omega^2$ Tangential acceleration: $a_{\text{t}} = r\alpha$

Rotational kinetic energy: $K = \dfrac{1}{2} I \omega^2$ Moment of inertia $I = \sum m_i r_i^2$

Kinetic energy of rolling motion: $K = \dfrac{1}{2} m v^2 + \dfrac{1}{2} I \omega^2 = \dfrac{1}{2} m v^2 \left[1 + \dfrac{I}{mr^2}\right]$

## Chapter 11: Rotational Dynamics and Static Equilibrium

Definition of torque: $\tau = rF \sin\theta$ $\theta$ is the angle between $\vec{\boldsymbol{r}}$ and $\vec{\boldsymbol{F}}$

Newton's Second Law: $\tau = I\alpha$

Conditions for Static Equilibrium: $\sum F_x = 0$ $\sum F_x = 0$ $\sum \tau = 0$

## Chapter 12: Gravity

Newton's Law of Gravitation: $F = G\dfrac{m_1 m_2}{r^2}$ $G = 6.67 \times 10^{-11}\ \text{N} \cdot \text{m}^2 / \text{kg}^2$

## Chapter 13: Oscillations about Equilibrium

Definition of a Period: $T$ = time to complete one cycle of a periodic motion

Frequency of Periodic Motion: $f = \dfrac{1}{T}$ units in cycle/second ≡ Hz

Simple Harmonic Motion: $x = A\cos\left(\frac{2\pi}{T}t\right)$ $\omega = \frac{2\pi}{T}$

$v = -A\omega\cos(\omega t)$ $a = -A\omega^2\cos(\omega t)$

Period of Mass on a Spring: $T = 2\pi\sqrt{\frac{m}{k}}$

Energy Conservation in Mass on a Spring System:

$$E = K + U = \frac{1}{2}mv^2 + \frac{1}{2}kx^2 \qquad E = U_{\max} = \frac{1}{2}kA^2 \qquad E = K_{\max} = \frac{1}{2}mv_{\max}^2$$

Period of Simple Pendulum: $T = 2\pi\sqrt{\frac{L}{g}}$

**Chapter 14: Waves and Sound**

Wavelength of a Wave: $\lambda$ = distance over which a wave repeats

Period of a Wave: $T$ = time required for one wavelength to pass a given point

Frequency of a Wave: $f = 1/T$

Speed of a Wave: $v = \lambda f$ Speed of a Wave on a String: $v = \sqrt{\frac{F_T}{m/L}} = \sqrt{\frac{F_T L}{m}}$

Sound Intensity: $I = \frac{E}{At} = \frac{P}{A}$ Point Source: $I = \frac{P}{4\pi r^2}$

Intensity Level (in dB): $\beta = 10\log(I/I_0)$ $I_0 = 10^{-12}$ W/m$^2$

Sources in phase: path difference = $\begin{cases} 0,\ \lambda,\ 2\lambda,\ 3\lambda,\ldots & \text{constructive interference} \\ \lambda/2,\ 3\lambda/2,\ 5\lambda/2,\ldots & \text{destructive interference} \end{cases}$

Standing Waves: Separation between two adjacent nodes = $\lambda/2$

Standing Waves on String: $f_n = n\frac{v}{2L}$ $n = 1,\ 2,\ 3,\ldots$

Standing Waves in Pipe closed at one end: $f_n = n\frac{v}{4L}$ $n = 1,\ 3,\ 5,\ldots$

Standing Waves in Pipe open at both ends: $f_n = n\frac{v}{2L}$ $n = 1,\ 2,\ 3,\ldots$

**Chapter 15: Fluids**

Definition of density: $\rho = \frac{M}{V}$ Definition of pressure: $P = \frac{F}{A}$

Variation of pressure with depth: $P_2 = P_1 + \rho gh$

Archimedes' Principle: Buoyant force $F_b = \rho_f gV$ where $V$ is the volume immersed in the fluid

Submerged Volume: $V_{sub} = V_s(\rho_s/\rho_f)$