Classical Mechanics – Master Formula Sheet

Essential definitions, laws, and equations for advanced problem solving

1. Kinematics

Velocity and acceleration as derivatives:

$$v = \frac{dx}{dt}, \quad a = \frac{dv}{dt} = v\frac{dv}{dx}$$

Constant acceleration equations ($a = \text{const}$):

$$v = v_0 + at$$

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

$$v^2 = v_0^2 + 2a(x - x_0)$$

2. Newton's Laws of Motion

Linear Momentum:

$$\mathbf{p} = m\mathbf{v}$$

Newton's Second Law:

$$\mathbf{F} = \frac{d\mathbf{p}}{dt} = m\mathbf{a}$$

Friction force:

$$f_s \le \mu_s N, \quad f_k = \mu_k N$$

3. Work, Energy, and Power

Work done by a force:

$$W = \int_{\mathbf{r}_1}^{\mathbf{r}_2} \mathbf{F} \cdot d\mathbf{r}$$

Kinetic Energy:

$$K = \frac{1}{2}mv^2 = \frac{p^2}{2m}$$

Potential Energy (Conservative Force):

$$\mathbf{F} = -\nabla U$$

Conservation of Mechanical Energy:

$$E = K + U = \text{const} \quad (\text{if } W_{\text{non-cons}} = 0)$$

Power:

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

4. Systems of Particles

Center of Mass:

$$\mathbf{R}_{cm} = \frac{\sum m_i \mathbf{r}_i}{\sum m_i} = \frac{1}{M}\int \mathbf{r}\, dm$$

Total Momentum:

$$\mathbf{P} = M\mathbf{V}_{cm} = \sum \mathbf{p}_i$$

Newton's Second Law for a System:

$$\mathbf{F}_{ext} = \frac{d\mathbf{P}}{dt} = M\mathbf{A}_{cm}$$

5. Rotational Motion

Angular velocity and acceleration:

$$\boldsymbol{\omega} = \frac{d\boldsymbol{\theta}}{dt}, \quad \boldsymbol{\alpha} = \frac{d\boldsymbol{\omega}}{dt}$$

Moment of Inertia:

$$I = \sum m_i r_i^2 = \int r^2\, dm$$

Parallel Axis Theorem:

$$I = I_{cm} + Md^2$$

Perpendicular Axis Theorem (Planar):

$$I_z = I_x + I_y$$

Torque:

$$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F} = \frac{d\mathbf{L}}{dt}$$

Angular Momentum:

$$\mathbf{L} = \mathbf{r} \times \mathbf{p} = I\boldsymbol{\omega}$$

Rotational Kinetic Energy:

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

6. Gravitation

Newton's Law of Gravitation:

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

Gravitational Potential Energy:

$$U = -G\frac{Mm}{r}$$

Kepler's Third Law:

$$T^2 = \left(\frac{4\pi^2}{GM}\right)a^3$$

7. Oscillations

Simple Harmonic Motion (SHM):

$$\frac{d^2x}{dt^2} + \omega^2 x = 0$$

Angular frequency:

$$\omega = \sqrt{\frac{k}{m}} = \frac{2\pi}{T} = 2\pi f$$

General Solution:

$$x(t) = A\cos(\omega t + \phi)$$

Energy in SHM:

$$E = \frac{1}{2}kA^2 = \frac{1}{2}mv^2 + \frac{1}{2}kx^2$$