Physics Formula Sheet

1. Newtonian Mechanics

Kinematics

- **Displacement**:
$$\vec{r} = x\hat{i} + y\hat{j} + z\hat{k}$$
- **Velocity**:
$$\vec{v} = \frac{d\vec{r}}{dt}, \quad v_{avg} = \frac{\Delta\vec{r}}{\Delta t}$$
- **Acceleration**:
$$\vec{a} = \frac{d\vec{v}}{dt}, \quad a_{avg} = \frac{\Delta\vec{v}}{\Delta t}$$
- **Projectile Motion**:
  - Range: $R = \frac{u^2 \sin 2\theta}{g}$
  - Max Height: $H = \frac{u^2 \sin^2\theta}{2g}$

Newton's Laws

- **First Law**: $\sum \vec{F} = 0 \Rightarrow \vec{v} = \text{constant}$
- **Second Law**: $\sum \vec{F} = m\vec{a}$
- **Third Law**: $\vec{F}_{12} = -\vec{F}_{21}$

Work & Energy

- **Work Done**:
$$W = \int \vec{F} \cdot d\vec{r}$$
- **Kinetic Energy**:
$$K = \frac{1}{2}mv^2$$
- **Potential Energy**:
$$U = mgh \text{ (gravitational)}, \quad U = \frac{1}{2}kx^2 \text{ (spring)}$$
- **Conservation of Energy**:
$$K_i + U_i = K_f + U_f$$

2. Rotational Dynamics

Angular Motion

- **Angular Displacement**:
$$\theta = \frac{s}{r} \text{ (radians)}$$
- **Angular Velocity**:
$$\omega = \frac{d\theta}{dt}, \quad \vec{v} = \vec{\omega} \times \vec{r}$$
- **Angular Acceleration**:
$$\alpha = \frac{d\omega}{dt}$$
- **Torque**:
$$\vec{\tau} = \vec{r} \times \vec{F}$$

Moment of Inertia

- **Definition**:
$$I = \sum m_i r_i^2$$
- **Parallel Axis Theorem**:
$$I = I_{cm} + Md^2$$
- **Perpendicular Axis Theorem**:
$$I_z = I_x + I_y$$

Rotational Energy & Power

- **Rotational KE**:
$$K = \frac{1}{2} I\omega^2$$
- **Power**:
$$P = \vec{\tau} \cdot \vec{\omega}$$

Angular Momentum

- **Definition**:
$$\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$$
- **Conservation**:
$$\text{If } \vec{\tau}_{ext} = 0, \; \vec{L} = \text{constant}$$

3. Central Forces & Orbits

Gravitation

- **Newton's Law**:
$$\vec{F} = -\frac{Gm_1m_2}{r^2}\hat{r}$$
- **Potential Energy**:
$$U = -\frac{Gm_1m_2}{r}$$
- **Escape Velocity**:
$$v_e = \sqrt{\frac{2GM}{R}}$$

Kepler's Laws

- **First Law**: Orbits are elliptical
- **Second Law**: $\frac{dA}{dt} = \text{constant}$
- **Third Law**:
$$T^2 \propto a^3$$

4. Oscillations

Simple Harmonic Motion (SHM)

- **Equation**:
$$\frac{d^2x}{dt^2} + \omega^2 x = 0$$
- **Solution**:
$$x(t) = A\cos(\omega t + \phi)$$
- **Energy**:
$$E = \frac{1}{2}kA^2$$

Damped & Forced Oscillations

- **Damped**:

$$\frac{d^2x}{dt^2} + 2\beta\frac{dx}{dt} + \omega_0^2 x = 0$$

- **Forced**:

$$\frac{d^2x}{dt^2} + 2\beta\frac{dx}{dt} + \omega_0^2 x = \frac{F_0}{m}\cos(\omega t)$$

5. Non-Inertial Frames

Fictitious Forces

- **Centrifugal Force**:

$$\vec{F}_{cf} = -m\vec{\omega} \times (\vec{\omega} \times \vec{r})$$

- **Coriolis Force**:

$$\vec{F}_{cor} = -2m\vec{\omega} \times \vec{v}'$$

6. Rigid Body Dynamics

Equations of Motion

- **Translation**:

$$\sum \vec{F} = M\vec{a}_{cm}$$

- **Rotation**:

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

Rolling Motion

- **Condition**:

$$v_{cm} = R\omega$$

- **KE**:

$$K = \frac{1}{2}Mv_{cm}^2 + \frac{1}{2}I_{cm}\omega^2$$

7. Elasticity & Fluids

Elasticity

- **Stress**:

$$\sigma = \frac{F}{A}$$

- **Strain**:

$$\epsilon = \frac{\Delta L}{L}$$

- **Young's Modulus**:

$$Y = \frac{\sigma}{\epsilon}$$

Fluid Mechanics

- **Bernoulli's Equation**:

$$P + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$$

- **Continuity Equation**:

$$A_1 v_1 = A_2 v_2$$

8. Special Relativity (Intro)

Lorentz Transformations

$$t' = \gamma\left(t - \frac{vx}{c^2}\right), \quad x' = \gamma(x - vt)$$

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

Relativistic Energy & Momentum

- **Momentum**:

$$\vec{p} = \gamma m \vec{v}$$

- **Energy**:

$$E = \gamma m c^2$$