Physics Booklet

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Classical Mechanics

1.1 Kinematics

1.1.1 Basic concepts

- Velocity

$$\overrightarrow{v}(t) = \frac{d\overrightarrow{r}}{dt}$$

  $\overrightarrow{r}(t)$: position

- Speed

$$v = |\overrightarrow{v}| = \left|\frac{d\overrightarrow{r}}{dt}\right|$$

- Acceleration

$$\overrightarrow{a}(t) = \frac{d\overrightarrow{v}}{dt}$$

- Other rates
  - Jerk

$$\overrightarrow{j}(t) = \frac{d\overrightarrow{a}}{dt}$$

  - Snap

$$\overrightarrow{s}(t) = \frac{d\overrightarrow{j}}{dt}$$

  - Crackle

$$\overrightarrow{c}(t) = \frac{d\overrightarrow{s}}{dt}$$

  - Pop

$$\overrightarrow{p}(t) = \frac{d\overrightarrow{c}}{dt}$$

1.1.2 Constant acceleration cases (theorems)

1. $v(t) = v_0 + at$

$$a = \frac{dv}{dt} \quad \therefore \quad \int_{t_0}^{t} a\,dt = \int_{t_0}^{t} \frac{dv}{dt}\,dt$$
$$\therefore \quad a \cdot (t - t_0) = [v(t)]_{t_0}^{t} \quad \therefore \quad v(t) = v_0 + at$$

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

$$v(t) = v_0 + at \quad \therefore \quad \int_{t_0}^{t} v(t)\,dt = \int_{t_0}^{t} (v_0 + at)\,dt$$
$$\therefore \quad x(t) = x_0 + v_0 t + \frac{at^2}{2}$$

3. $x(t) = x_0 + vt - \frac{at^2}{2}$

$$v = v_0 + at \quad \therefore \quad v_0 = v - at$$
$$\therefore \quad x(t) = x_0 + (v - at)t + \frac{at^2}{2} \quad \therefore \quad x(t) = x_0 + vt - \frac{at^2}{2}$$

4. $x(t) = x_0 + \frac{(v_0+v)t}{2}$

$$2x = x(t) + x(t) = \left(x_0 + v_0 t + \frac{at^2}{2}\right) + \left(x_0 + vt - \frac{at^2}{2}\right)$$
$$\therefore \quad 2x = 2x_0 + v_0 t + vt \quad \therefore \quad x(t) = x_0 + \frac{(v_0 + v)t}{2}$$

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

$$\begin{cases} v(t) = v_0 + at \\ x(t) = x_0 + \frac{(v_0+v)t}{2} \end{cases} \quad \therefore \quad \begin{cases} v - v_0 = at \\ v + v_0 = \frac{2(x-x_0)}{t} \end{cases}$$
$$\therefore \quad v^2 = v_0^2 + 2a(x - x_0)$$

1.1.3 Uniform circular motion

- Angular velocity

$$\omega = \frac{d\theta}{dt}$$

- Position

$$\overrightarrow{r}(t) = R\cos(\omega t)\hat{i} + R\sin(\omega t)\hat{j}$$

- Velocity

$$\overrightarrow{v}(t) = -\omega R\sin(\omega t)\hat{i} + \omega R\cos(\omega t)\hat{j}$$

- Speed

$$v = \omega R$$

- Centripetal acceleration

$$\overrightarrow{a} = -\omega^2 \overrightarrow{r}$$
$$a = \omega^2 R = \frac{v^2}{R}$$

1.2 Forces

1.2.1 Newton's Laws

1. Inertia

Every object moves in a straight line unless acted upon by a force.

2. $F = ma$

$$\overrightarrow{F}_{net} = \sum \overrightarrow{F} = m\overrightarrow{a}$$

3. Action and reaction

For every action, there is an equal and opposite reaction

1.2.2 Weight | Near-Earth gravitional force (W)

- Definition

$$\overrightarrow{W} = -mg\hat{k}$$

- Gravity

$$g \approx 9.81 \, \frac{m}{s^2} \quad \text{(downward)}$$

1.2.3 Tension (T)

- Definition

  Pulling force transmitted axially by the means of a rope to keep it from changing its length.

- Ideal rope
  - massless
  - doesn't stretch or break

1.2.4 Normal force (N)

- Definition

  Contact force orthogonal to a surface that keeps two solid objects from passing through each other.

1.2.5 Friction

- Definition

  Resistance to sliding at an interface.

- Static friction

$$\left|\overrightarrow{F_s}\right| \leq \mu_s N$$

  μ_s: coefficient of static friction

- Kinectic friction

$$\left|\overrightarrow{F_k}\right| = \mu_k N$$

  μ_k: coefficient of kinectic friction

- General relation between constants

$$\mu_s > \mu_k$$

1.2.6 Drag (D)

- Viscous force (linear drag)

$$D \propto v$$

- Air resistance (quadratic drag)

$$D = \frac{1}{2} C \rho A v^2$$

  C: drag coefficient (associated with shape)
  ρ: mass density of air
  A: cross-section surface area

- Terminal speed

$$v_t = \sqrt{\frac{2mg}{C\rho A}}$$

1.2.7 Spring force

- Hooke's law

$$F = -kx$$

1.3 Energy

1.4 Momentum

1.5 Angular momentum

1.6 Lagrangian method

Relativistic Mechanics

Electromagnetism

Thermodynamics

Statistical mechanics

Quantum mechanics