

Physics Booklet

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Classical Mechanics

1.1 Kinematics

1.1.1 Basic concepts

- Velocity

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

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

- Speed

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

- Acceleration

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

- Other rates

– Jerk

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

– Snap

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

– Crackle

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

– Pop

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

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

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

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

$$v = v_0 + at \quad \therefore \quad v_0 = v - at$$

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

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

$$2x = x(t) + x(t) = \left(x_0 + v_0t + \frac{at^2}{2}\right) + \left(x_0 + vt - \frac{at^2}{2}\right)$$

$$\therefore 2x = 2x_0 + v_0t + vt \quad \therefore \quad x(t) = x_0 + \frac{(v_0 + v)t}{2}$$

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

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

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

1.1.3 Uniform circular motion

- Angular velocity

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

- Position

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

- Velocity

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

- Speed

$$v = \omega R$$

- Centripetal acceleration

$$\vec{a} = -\omega^2 \vec{r}$$

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

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. $F = ma$

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

3. Action and reaction

For every action, there is an equal and opposite reaction

1.2.2 Weight | Near-Earth gravitational force (W)

- Definition

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

- 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

$$\left| \vec{F}_s \right| \leq \mu_s N$$

μ_s : coefficient of static friction

- Kinetic friction

$$\left| \vec{F}_k \right| = \mu_k N$$

μ_k : coefficient of kinetic 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

1.3.1 Basic concepts

- Work (W)

$$W = \int \vec{F} \bullet d\vec{r}$$

- Kinetic energy (K)

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

- Potential energy (U)

$$\Delta U = - \int \vec{F}_{cons} \bullet d\vec{r} = -\Delta W_{cons}$$

- Spring

$$U = \frac{1}{2}kx^2$$

- Weight

$$U = mgz$$

- Work-Energy theorem

$$W_{net} = \Delta K$$

- Derivation

$$\begin{aligned} W_{net} &= \int_i^f F_{net} dx = m \int_i^f \frac{dx}{dt} dv = m \int_i^f v dv \\ \therefore W_{net} &= \left[\frac{mv^2}{2} \right]_i^f = \Delta K \end{aligned}$$

1.3.2 Conservation of energy

- Definition

$$E_T = K + U = \text{constant}$$

$$\Delta E_T = \Delta K + \Delta U = 0$$

if there's no dissipative force

- Conservative forces requirements

- the force has to depend only on the position of objects
- work done by the force has to depend only on the initial and final states of a system (not on how it got from initial to final)

- Work done by dissipative forces

$$W_{diss} = \Delta E_T$$

- Derivation

$$W_{net} = W_{cons} + W_{diss} = -\Delta U + W_{diss} = \Delta K$$

$$\therefore W_{diss} = \Delta K + \Delta U = \Delta E_T$$

1.3.3 Work done by conservative forces

1. Spring force

$$W = \frac{1}{2}kx_i^2 - \frac{1}{2}kx_f^2 = \frac{k}{2}(x_i^2 - x_f^2)$$

2. Weight

$$W = -mg\Delta z$$

1.4 Momentum

1.5 Angular momentum

1.6 Lagrangian method

Relativistic Mechanics

Electromagnetism

Thermodynamics

Statistical mechanics

Quantum mechanics