Physics Handout 1

International Physics Olympiad Reference

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1. Kinematics

Equations of motion

$$v = v_0 + at, \quad x = x_0 + v_0 t + \frac{1}{2}at^2, \quad v^2 = v_0^2 + 2a\Delta x$$

Projectile motion

$$R = \frac{v_0^2 \sin(2\theta)}{g}, \qquad H = \frac{v_0^2 \sin^2\theta}{2g}$$

Trick: use symmetry; time up = time down.

Circular motion

$$a_c = \frac{v^2}{r} = \omega^2 r, \quad T = \frac{2\pi}{\omega}$$

Quick Tricks

- Use vector decomposition early.
- Pick coordinate so that one acceleration disappears.
- For projectiles, work in parametric form $(x(t), y(t))$.

2. Dynamics

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

Friction

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

Impulse–momentum

$$\Delta\vec{p} = \int \vec{F}\, dt$$

Collision shortcuts

- 1D elastic collision:

$$v_1' = \frac{m_1 - m_2}{m_1 + m_2}v_1 + \frac{2m_2}{m_1 + m_2}v_2$$

- Relative velocity reverses in elastic collisions.
- In multi-step collisions: isolate pairwise events.

Pulley Tricks

- Count rope segments pulling each mass → acceleration relation.
- Constraint: "length of rope constant" → derive kinematic relations.

3. Energy

$$W = \int \vec{F} \cdot d\vec{s}, \qquad K = \frac{1}{2}mv^2, \qquad U = mgh$$

Springs

$$U = \frac{1}{2}kx^2, \qquad F = -kx$$

Shortcut: use energy instead of forces for turning-points.

Mechanical energy conservation

$$K_i + U_i = K_f + U_f \quad \text{(if no nonconservative work)}$$

4. Rotational Dynamics

$$\tau = I\alpha, \quad L = I\omega, \quad K_{\text{rot}} = \tfrac{1}{2}I\omega^2$$

Common moments of inertia

$$I_{\text{rod, end}} = \frac{1}{3}ML^2, \qquad I_{\text{disk}} = \frac{1}{2}MR^2, \qquad I_{\text{sphere}} = \frac{2}{5}MR^2$$

Rolling without slipping

$$v = \omega R$$

Tricks

- Choose pivot to kill a torque term.
- Use energy when friction is static (no energy loss).

5. Oscillations

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

Pendulum

$$T \approx 2\pi\sqrt{\frac{L}{g}} \qquad (\theta \ll 1)$$

Damped

$$x(t) = Ae^{-\gamma t}\cos(\omega' t + \phi), \quad \gamma = \frac{b}{2m}$$

6. Mechanical Waves

$$v = \lambda f = \sqrt{\frac{T}{\mu}}$$

Interference

$$\Delta L = n\lambda \quad (\textit{constructive}), \qquad \Delta L = (n+\tfrac{1}{2})\lambda \quad (\textit{destructive})$$

Doppler (sound)

$$f' = f\frac{v \pm v_o}{v \mp v_s}$$

7. Fluids

$$p = p_0 + \rho g h$$
$$F_B = \rho V g$$

Continuity

$$A_1 v_1 = A_2 v_2$$

Bernoulli

$$p + \frac{1}{2}\rho v^2 + \rho g h = \text{const}$$

Shortcuts:

- Use streamline; avoid mixing points off-streamline.
- In many IPhO problems, viscosity is negligible unless stated.

8. Thermodynamics

$$pV = nRT$$

First law

$$\Delta U = Q - W$$

Work in isothermal

$$W = nRT \ln \frac{V_f}{V_i}$$

Adiabatic

$$pV^\gamma = \text{const}, \qquad TV^{\gamma-1} = \text{const}$$

Tricks:

- Use indicator diagrams (P–V) to visualize sign of work.
- Write everything in terms of T if C_V, C_P appear.

9. Electrostatics

$$F = \frac{1}{4\pi\epsilon_0}\frac{q_1 q_2}{r^2}, \qquad \vec{E} = \frac{\vec{F}}{q}$$

Potential

$$V = -\int \vec{E} \cdot d\vec{s}$$

Capacitance

$$C = \frac{\epsilon_0 A}{d}, \qquad U = \frac{1}{2}CV^2$$

10. DC Circuits

$$V = IR, \qquad P = IV = I^2R = \frac{V^2}{R}$$

Kirchhoff

$$\sum V = 0, \qquad \sum I_{\text{node}} = 0$$

Shortcut: reduce series–parallel first; then node method.

11. Magnetism

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I\, d\vec{\ell} \times \hat{r}}{r^2}$$

Flux & Induction

$$\mathcal{E} = -\frac{d\Phi}{dt}, \qquad \Phi = \int \vec{B} \cdot d\vec{A}$$

Shortcuts:

- Increasing flux → induced emf opposes increase.
- Motional emf: $\mathcal{E} = Blv$ (straight rod).

12. Geometric Optics

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

Thin film interference

$$2t = (m + \tfrac{1}{2})\lambda \quad \text{(destructive for reflection)}$$

13. Modern Physics

$$E = mc^2, \qquad E = hf, \qquad \lambda = \frac{h}{p}$$

Photoelectric effect

$$K_{\max} = hf - \phi$$

Bohr model

$$E_n = -\frac{13.6\ \text{eV}}{n^2}$$

14. Math Tools

$$\int x^n dx = \frac{x^{n+1}}{n+1}, \qquad \int e^{ax} dx = \frac{1}{a}e^{ax}$$

Small-angle

$$\sin\theta \approx \theta, \qquad \cos\theta \approx 1 - \frac{\theta^2}{2}$$

Binomial

$$(1+x)^n \approx 1 + nx, \quad |x| \ll 1$$

15. Methods & Tricks

1. Conservation First

- Try momentum/energy before forces.
- For explosions: center of mass continues same motion.

2. Choose Clever Frames

- Free-falling frame eliminates mg.
- COM frame simplifies collisions drastically.

3. Differential Tricks

$$\text{If } F(x) \text{ varies: } W = \int F(x)\, dx$$

4. Diagram First

Every multi-body system begins with 3 steps:

1. Draw FBDs.
2. Write constraints (rope lengths).
3. Apply Newton or Energy.

5. Scaling

If uncertain:

$$T \propto \sqrt{\frac{L}{g}}, \qquad v \propto \sqrt{E}$$