Physics Handout 2

Comprehensive Formula Reference

Tawhid Bin Omar

March 10, 2026

Quick Constants

- $c = 2.997\,924\,58 \times 10^{8}\,\mathrm{m\,s^{-1}}$ (speed of light)
- $g = 9.806\,65\,\mathrm{m\,s^{-2}}$ (standard gravity)
- $G = 6.674\,30 \times 10^{-11}\,\mathrm{m^{3}\,kg^{-1}\,s^{-2}}$ (grav. const.)
- $k_B = 1.380\,649 \times 10^{-23}\,\mathrm{J\,K^{-1}}$ (Boltzmann)
- $\epsilon_0 = 8.854\,187\,812\,8 \times 10^{-12}\,\mathrm{F\,m^{-1}}$; $\mu_0 = 4\pi \times 10^{-7}$ H.m^{-1}
- $R = 8.314\,462\,618\,\mathrm{J\,mol^{-1}\,K^{-1}}$ (gas constant)

Kinematics

Displacement / velocity / acceleration:

$$v = v_0 + at, \qquad x = x_0 + v_0 t + \tfrac{1}{2}at^2,$$
$$v^2 = v_0^2 + 2a(x - x_0).$$

Projectile (range without air):

$$R = \frac{v_0^2 \sin(2\theta)}{g}.$$

Uniform circular motion:

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

Dynamics

Newton's laws: $\mathbf{F}_{\text{net}} = m\mathbf{a}$.

Friction: $f_{s,\max} = \mu_s N, \quad f_k = \mu_k N$.

Momentum: $\mathbf{p} = m\mathbf{v}, \quad \Delta\mathbf{p} = \int \mathbf{F}\,dt$.

Collisions: elastic: kinetic energy conserved; inelastic: $\mathbf{p}_{\text{tot}}$ conserved, $\Delta E_{\text{mech}} \le 0$.

Work & Energy

$$W = \int \mathbf{F}\cdot d\mathbf{s}, \quad K = \tfrac{1}{2}mv^2, \quad U = mgh.$$

Spring: $U_s = \frac{1}{2}kx^2, \quad F_s = -kx$.

Conservation: $E_{\text{tot}} = K + U + (\text{other}) = \text{const}$ (isolated).

Rotational Motion

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

$I_{\text{solid cylinder}} = \frac{1}{2}MR^2$, $I_{\text{solid sphere}} = \frac{2}{5}MR^2$.

Rolling without slipping: $v_{\text{CM}} = \omega R$.

Oscillations & Waves

Simple harmonic oscillator: $m\ddot{x} + kx = 0$, $\omega = \sqrt{\dfrac{k}{m}}$.

$x(t) = A\cos(\omega t + \phi), \quad E = \frac{1}{2}kA^2$.

Wave speed: $v = \lambda f$.

Damped: $x(t) = Ae^{-\gamma t}\cos(\omega' t + \phi)$,

$$\gamma = \frac{b}{2m}.$$

Fluids

$p = p_0 + \rho g h, \quad F_B = \rho_{\text{fluid}} V g$.

Continuity: $A_1 v_1 = A_2 v_2$.

Bernoulli (incompressible, steady): $p + \frac{1}{2}\rho v^2 + \rho g h = \text{const}$.

Thermodynamics

Ideal gas: $pV = nRT = Nk_BT$.

$\Delta U = Q - W$ (sign conv.: W = work by system).

First law (cycles): $\oint dQ = \oint dW$.

Isothermal: $W = nRT \ln \frac{V_f}{V_i}$.

Adiabatic (ideal gas): $pV^\gamma = \text{const}$, $TV^{\gamma-1} = \text{const}$.

Electrostatics & Circuits

Coulomb: $F = \frac{1}{4\pi\epsilon_0}\frac{q_1q_2}{r^2}$.

Field: $\mathbf{E} = \frac{\mathbf{F}}{q}$, $V = -\int \mathbf{E}\cdot d\mathbf{s}$.

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

Ohm's law: $V = IR$, $P = IV = I^2R = \frac{V^2}{R}$.

Kirchhoff: $\sum V = 0$, $\sum I_{\text{node}} = 0$.

Magnetism & Induction

$$\Phi_B = \int \mathbf{B}\cdot d\mathbf{A}, \quad \mathcal{E} = -\frac{d\Phi_B}{dt}.$$

Lorentz force: $\mathbf{F} = q(\mathbf{E} + \mathbf{v}\times\mathbf{B})$.

Ampere/ Biot–Savart: $d\mathbf{B} = \frac{\mu_0}{4\pi}\frac{I d\mathbf{l}\times\hat{r}}{r^2}$.

Optics & Waves

Snell: $n_1 \sin\theta_1 = n_2 \sin\theta_2$.

Thin lens: $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$.

Doppler (approx, sound): $f' = f\left(\frac{v \pm v_{\text{obs}}}{v \mp v_{\text{src}}}\right)$.

Modern Physics (select)

$$E = mc^2, \quad p = \frac{E}{c} \text{ (ultrarelativistic).}$$

Photoelectric: $E_{\text{kin,max}} = hf - \phi$.

de Broglie: $\lambda = \frac{h}{p}$.

Mathematical Tools & Approximations

- Small-angle: $\sin\theta \approx \theta$, $\cos\theta \approx 1 - \frac{\theta^2}{2}$ for $\theta \ll 1$.
- Binomial: $(1+x)^n \approx 1 + nx$ for $|x| \ll 1$.
- Taylor (1D): $f(x) \approx f(0) + f'(0)x + \frac{1}{2}f''(0)x^2$.
- Integrals often via separation of variables; dimension-check every expression.

Problem-Solving Templates

Type 1 — Direct application (3–4 pts)

1. Identify knowns and desired quantity.
2. Choose direct formula; substitute.
3. Check units and significant figures.

Type 2 — Two-step (4–6 pts)

1. Express intermediate variable(s).
2. Solve intermediate, then final; watch conserved quantities.

Type 3 — Conservation / Energy

1. Write energy/momentum conservation; choose frame to simplify.
2. Solve symbolically before plugging numbers.

Type 4 — Differential/Integration

1. Set up differential equation, separate variables if possible.
2. Integrate with bounds; apply initial conditions.

Common Pitfalls & Quick Checks

- **Hidden constraints:** check wording for 'constant volume', 'negligible air', 'steady state'.
- **Frame choice:** switching frame can linearize the algebra.
- **Limit checks:** check $t \to 0$, $m \to 0$, $v \to 0$ where appropriate.
- **Units:** always do dimensional analysis on final formula.

Compact Example (template)

Problem X Short title 5 points

Given: list givens.

Solution

Define variables, state assumptions.
Key equation:

$$F = ma$$

Solve symbolically, then numerically:

$$a = \frac{F}{m},$$
$$t = \sqrt{\frac{2s}{a}}.$$
$$\Rightarrow t = \text{(value) s}$$

Appendix: Useful Integrals and Sums

$$\int x^n dx = \frac{x^{n+1}}{n+1} + C, \quad (n \neq -1).$$
$$\int e^{ax} dx = \frac{1}{a} e^{ax} + C.$$
$$\sum_{k=0}^{N} ar^k = a\frac{1 - r^{N+1}}{1 - r}.$$
