The Theoretical Minimum for High School Physics

The core concepts and equations needed for solid conceptual mastery and problem-solving at the typical high-school / introductory college-prep level (CBSE Class 11–12, AP Physics 1/2, A-level, or equivalent). It emphasizes physical understanding, conservation laws, and the most frequently used relations rather than exhaustive coverage.

1. Kinematics (Description of Motion)

Concepts: Position, displacement, velocity, acceleration; average vs. instantaneous; uniform and uniformly accelerated motion; free fall; relative velocity; projectile motion (range, time of flight, trajectory); circular motion (centripetal acceleration).

Key equations:

- $v = u + at$
- $s = ut + \frac{1}{2}at^2$
- $v^2 = u^2 + 2as$
- $s = \dfrac{u+v}{2}\,t$
- Projectile: $R = \dfrac{u^2 \sin 2\theta}{g}, \quad H = \dfrac{u^2 \sin^2\theta}{2g}$
- Centripetal: $a_c = \dfrac{v^2}{r} = \omega^2 r$

2. Newton's Laws & Dynamics

Concepts: Inertia, force, mass vs. weight; free-body diagrams; action–reaction; friction (static/kinetic); tension, normal force; pseudo-forces in non-inertial frames; connected systems; circular motion dynamics.

Key equations:

- $\vec{F} = m\vec{a}$ (and component form)
- $f_s \le \mu_s N, \quad f_k = \mu_k N$
- $F_c = \dfrac{mv^2}{r}$

3. Work, Energy & Power

Concepts: Work by constant/variable force; kinetic & potential energy; work–energy theorem; conservation of mechanical energy; power; conservative vs. non-conservative forces.

Key equations:

- $W = \vec{F} \cdot \vec{s} = Fs\cos\theta$
- $K = \frac{1}{2}mv^2$
- $U_g = mgh$ (near Earth), $\quad U = \frac{1}{2}kx^2$ (spring)

- $W_{\text{net}} = \Delta K$
- $P = \dfrac{dW}{dt} = Fv$

4. Linear Momentum & Collisions

Concepts: Momentum, impulse–momentum theorem; conservation of linear momentum; elastic vs. inelastic collisions; center of mass.

Key equations:

- $\vec{p} = m\vec{v}$
- $\vec{J} = \Delta\vec{p} = \vec{F}_{\text{avg}}\Delta t$
- $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$ (1-D)

5. Rotational Motion & Gravitation

Concepts: Torque, moment of inertia, angular momentum; rotational analogues of Newton's laws; rolling without slipping; Kepler's laws; Newton's law of gravitation; escape velocity, orbital velocity.

Key equations:

- $\tau = I\alpha, \quad \tau = rF\sin\theta$
- $L = I\omega$
- $I = \sum mr^2$ (or standard formulas for common shapes)
- $F = G\dfrac{m_1m_2}{r^2}$
- $v_{\text{esc}} = \sqrt{\dfrac{2GM}{R}}, \quad v_{\text{orb}} = \sqrt{\dfrac{GM}{r}}$

6. Simple Harmonic Motion & Waves

Concepts: Restoring force, amplitude, period, frequency, phase; energy in SHM; superposition; progressive waves; sound (speed, Doppler effect, beats); standing waves on strings/pipes.

Key equations:

- $F = -kx, \quad T = 2\pi\sqrt{\dfrac{m}{k}}, \quad T = 2\pi\sqrt{\dfrac{l}{g}}$
- $v = f\lambda$
- $v_{\text{sound}} = \sqrt{\dfrac{\gamma P}{\rho}}$ or $\sqrt{\dfrac{B}{\rho}}$
- Doppler: $f' = f\dfrac{v \pm v_o}{v \pm v_s}$

7. Fluids & Thermodynamics

Concepts: Pressure, buoyancy (Archimedes), Bernoulli's principle; ideal-gas law; kinetic theory (pressure & temperature from molecular motion); first law of thermodynamics; specific heat, latent heat; heat

engines (efficiency).

Key equations:

- $P = \rho g h, \quad F_B = \rho V g$
- $PV = nRT$
- $\Delta U = Q - W$ (or $Q + W$ depending on sign convention)
- $\frac{1}{2} m v_{\text{rms}}^2 = \frac{3}{2} kT$

8. Electrostatics & Current Electricity

Concepts: Coulomb's law, electric field & potential, capacitance; Ohm's law, resistivity, series/parallel circuits, Kirchhoff's rules; power in circuits; EMF and internal resistance.

Key equations:

- $F = k \dfrac{q_1 q_2}{r^2}$
- $E = \dfrac{F}{q}, \quad V = Ed$ (uniform field)
- $C = \dfrac{Q}{V}, \quad U = \frac{1}{2} C V^2$
- $V = IR, \quad R = \rho \dfrac{l}{A}$
- $P = VI = I^2 R = \dfrac{V^2}{R}$

9. Magnetism & Electromagnetic Induction

Concepts: Magnetic force on moving charges and currents; magnetic field of wires, loops, solenoids; Faraday's law, Lenz's law; self/mutual inductance; AC basics (rms, impedance of R, L, C).

Key equations:

- $\vec{F} = q(\vec{v} \times \vec{B}), \quad F = IlB \sin\theta$
- $B = \dfrac{\mu_0 I}{2\pi r}$ (long straight wire)
- $\mathcal{E} = -\dfrac{d\Phi_B}{dt}$
- $\mathcal{E} = -L \dfrac{dI}{dt}$

10. Optics

Concepts: Reflection, refraction (Snell's law), total internal reflection; lenses and mirrors (ray diagrams, magnification); interference (Young's double slit), diffraction, polarization; wave nature of light.

Key equations:

- $\dfrac{1}{f} = \dfrac{1}{v} - \dfrac{1}{u}$ (Cartesian sign convention)

- $n_1 \sin i = n_2 \sin r$
- $\beta = \dfrac{\lambda D}{d}$ (fringe width)

11. Modern Physics Essentials

Concepts: Photoelectric effect (Einstein's equation), de Broglie wavelength; Bohr model of H-atom; nuclear structure, radioactivity (decay law), binding energy; basic semiconductor ideas (optional at pure theoretical-minimum level).

Key equations:

- $hf = \phi + K_{\max}$
- $\lambda = \dfrac{h}{p}$
- $E_n = -\dfrac{13.6}{n^2}\,\text{eV}$
- $N = N_0 e^{-\lambda t}, \quad T_{1/2} = \dfrac{\ln 2}{\lambda}$

Minimal Supporting Mathematics

- Vectors (addition, components, dot & cross products)
- Basic calculus for rates of change and areas under curves (velocity from acceleration, work from force, etc.) where introduced
- Graphs of motion, energy, and fields
- Significant figures, dimensional analysis, and order-of-magnitude estimation

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This set is deliberately lean: mastery of the concepts and fluent use of the listed equations allow a student to tackle virtually any standard high-school physics problem and provide the conceptual foundation for first-year university physics. Advanced topics (special relativity, quantum mechanics beyond the Bohr model, Maxwell's equations in differential form, etc.) lie outside the high-school theoretical minimum.