Physics Handout 5

Problem Classification & Strategy Guide

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MECHANICS (35% of Problems)

Kinematics (3-4 pts)

HRK: Ch 2: Motion in 1D, Ch 3: Vectors, Ch 4: Motion in 2D

Key Problems:

- **E2-24, E2-26:** Average speed calculations
- **E2-41, E2-45:** Acceleration problems
- **P2-9:** Instantaneous vs average velocity

Constant Acceleration: $v^2 = v_0^2 + 2ax$

Projectile Peak: $t = \frac{v_0 \sin\theta}{g}$

PB Pattern: Time-speed-distance triangulation

Trick: Use $v_{avg} = \frac{v_i + v_f}{2}$ for constant a

Competition Examples:

- **PB 2024 #1:** Sound delay in sprint (E2-24 analog)
- **PB 2024 #11:** Video playback acceleration
- **PB 2023 #11:** Mower cable wind-up

Forces & Dynamics (4-6 pts)

HRK: Ch 5: Force & Motion, Ch 6: Force & Motion II

Key Problems:

- **E3-9, E3-11:** Two-body acceleration
- **E3-17, E3-18:** Net force calculations
- **P3-12:** Pulley systems (critical!)

Newton's 2nd: $F_{\text{net}} = ma$

Friction: $f \leq \mu N$

Always draw free-body diagrams!

Trick: For pulleys: tension same throughout massless rope

Competition Examples:

- **PB 2024 #15:** Blocks with friction
- **PB 2024 #43:** Hill carts (pulley variant)
- **PB 2023 #17:** Elastic rope pulleys

Energy & Work (5-7 pts)

HRK: Ch 7: Work & Kinetic Energy, Ch 8: Conservation of Energy

Key Problems:

- **E7-15, E7-20:** Work-energy theorem
- **E8-12, E8-14:** Spring potential energy
- **P8-15:** Complex energy conservation

Work-Energy: $W = \Delta KE = \frac{1}{2}m(v_f^2 - v_i^2)$

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

PB loves reference frame tricks!

Trick: Moving to spring's frame often simplifies

Competition Examples:

- **PB 2024 #10:** Spring dynamics (HRK P8-15!)
- **PB 2023 #10:** Pickpocket spring
- **PB 2024 H-series:** Buoyancy work problems

Rotational Motion (6-8 pts)

HRK: Ch 11: Rotation, Ch 12: Rolling, Torque, Angular Momentum

Key Problems:

- **E11-15, E11-18:** Rotational kinematics
- **E12-8, E12-12:** Rolling motion
- **P12-15:** Moment of inertia problems

Rotational KE: $KE = \frac{1}{2}I\omega^2$

Rolling: $v = \omega r$ (no slip)

Don't forget I depends on axis!

Trick: Parallel axis theorem: $I = I_{cm} + md^2$

Competition Examples:

- **PB 2024 #22:** Rolling glass cylinder
- **PB 2023 #22:** Taxidermy cylinder
- **PB 2024 #44:** Loose ring oscillation

FLUIDS & THERMODYNAMICS (25%)

Fluid Statics (4-5 pts)

HRK: Ch 15: Fluids

Key Problems:

- **E15-8, E15-12:** Buoyancy (Archimedes)
- **E15-15:** Pressure vs depth
- **P15-12:** Floating objects

Buoyancy: $F_b = \rho_{\text{fluid}} V_{\text{displaced}} g$

Pressure: $p = p_0 + \rho gh$

Volume changes with immersion depth!

Trick: Center of buoyancy ≠ center of gravity

Competition Examples:

- **PB 2024 H.1-H.4:** Progressive buoyancy problems
- **PB 2024 #41:** Isothermal bubble compression
- **PB 2023 #15:** Steel sphere float

Fluid Dynamics (5-6 pts)

HRK: Ch 15: Fluids (Bernoulli)

Key Problems:

- **E15-22, E15-25:** Bernoulli equation
- **E15-28:** Torricelli's law
- **P15-25:** Flow rate problems

Bernoulli: $p + \frac{1}{2}\rho v^2 + \rho gh = \text{const}$

Torricelli: $v = \sqrt{2gh}$

Bernoulli only for streamline flow!

Trick: Use energy conservation as backup

Competition Examples:

- **PB 2024 #12:** Bottle crack spray
- **PB 2024 #39:** Hourglass water flow
- **PB 2023 #29:** Archerfish targeting

Thermodynamics (5-7 pts)

HRK: Ch 19: Temperature, Ch 20: Heat, Ch 21: Kinetic Theory

Key Problems:

- **E20-12, E20-15:** Heat transfer
- **E21-8, E21-12:** Ideal gas law
- **P21-15:** Gas processes (iso- variations)

Ideal Gas: $pV = nRT$

Heat: $Q = mc\Delta T$

Check for phase changes!

Trick: Vapor pressure often matters (PB #31)

Competition Examples:

- **PB 2024 #31:** Argon measurement
- **PB 2024 #49:** Maximum compression
- **PB 2023 #25:** Ice in sealed cube

ELECTROMAGNETISM (20%)

Electrostatics (4-5 pts)

HRK: Ch 23: Electric Fields, Ch 24: Gauss's Law, Ch 25: Potential

Key Problems:

- **E23-15, E23-18:** Electric field calculations
- **E25-12, E25-15:** Potential difference
- **P25-20:** Potential from charge distributions

Coulomb: $F = k\frac{q_1 q_2}{r^2}$

Potential: $V = \frac{kq}{r}$

Infinite series often appear!

Trick: Recognize geometric series: $\sum r^n = \frac{1}{1-r}$

Competition Examples:

- **PB 2024 #30:** Concentric spheres
- **PB 2024 #37:** Dipole in B-field
- **PB 2023 #8:** Schwarzschild black hole

Circuits (4-6 pts)

HRK: Ch 27: Circuits, Ch 28: RC Circuits, Ch 29: Magnetic Fields

Key Problems:

- **E27-15, E27-20:** Kirchhoff's laws

- **E28-8, E28-12:** RC charging/discharging
- **P27-25:** Complex circuit reduction

Ohm's Law: $V = IR$

RC Decay: $\tau = RC$

Infinite resistor networks use recursion!

Trick: Replace network with equivalent R_{tot}

Competition Examples:

- **PB 2024 #24:** Infinite resistance triangles
- **PB 2024 #36:** Infinite resistance variant
- **PB 2023 #14:** Voltage divider

Magnetism (5-7 pts)

HRK: Ch 29: Magnetic Fields, Ch 30: Magnetic Induction

Key Problems:

- **E29-12, E29-18:** Lorentz force
- **E30-15, E30-20:** Faraday's law
- **P30-22:** Motional EMF

Lorentz: $F = q(v \times B)$

Faraday: $\mathcal{E} = -\frac{d\Phi_B}{dt}$

Right-hand rule for cross products!

Trick: Magnetic mirror formula for PB #51

Competition Examples:

- **PB 2024 #18:** Combined springs & wires
- **PB 2023 #51:** Van Allen belts
- **PB 2024 #9:** Induction heating

WAVES & OPTICS (10%)

Waves (3-4 pts)

HRK: Ch 17: Waves I, Ch 18: Waves II

Key Problems:

- **E17-15, E17-20:** Wave equation
- **E18-12, E18-15:** Doppler effect
- **P18-20:** Sound intensity

Wave Speed: $v = f\lambda$

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

Sign convention in Doppler!

Trick: Use relative velocity for moving source/observer

Competition Examples:

- **PB 2024 #27:** Insidious horn (Doppler)
- **PB 2024 #31:** Echo timing
- **PB 2023 #31:** Echo in tunnel

Optics (4-6 pts)

HRK: Ch 34: Images, Ch 35: Interference, Ch 36: Diffraction

Key Problems:

- **E34-12, E34-18:** Lens equation
- **E35-15:** Interference patterns
- **P34-25:** Compound optical systems

Thin Lens: $\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$

Magnification: $m = -\frac{s_i}{s_o}$

Sign conventions crucial!

Trick: Virtual images: $s_i < 0$

Competition Examples:

- **PB 2024 #45:** Lake on mirror
- **PB 2024 #48:** Oscillating lens
- **PB 2023 #16:** Polarization degree

MODERN PHYSICS (10%)

Relativity (6-7 pts)

HRK: Ch 37: Relativity

Key Problems:

- **E37-8, E37-12:** Time dilation
- **E37-18, E37-22:** Length contraction
- **P37-25:** Relativistic energy

Time Dilation: $\Delta t = \gamma \Delta t_0$

Energy: $E^2 = (pc)^2 + (mc^2)^2$

Use energy-momentum when $v \approx c$

Trick: $\gamma \approx 1 + \frac{1}{2}\beta^2$ for $\beta \ll 1$

Competition Examples:

- **PB 2024 #43:** Electron collision
- **PB 2023 #35:** Relativistic star
- **PB 2024 M.4:** Relativistic driving (!)

Quantum (7-9 pts)

HRK: Ch 38: Photons, Ch 39: Waves/Particles, Ch 40: Quantum Mechanics

Key Problems:

- **E38-12, E38-18:** Photoelectric effect
- **E40-15, E40-20:** Wave functions
- **P40-25:** Quantum harmonic oscillator

Photon Energy: $E = hf = \frac{hc}{\lambda}$

De Broglie: $\lambda = \frac{h}{p}$

Boltzmann distribution for thermal systems

Trick: $Z = \sum e^{-E_n/k_B T}$ (partition function)

Competition Examples:

- **PB 2024 #50:** Quantum oscillator optimization
- **PB 2024 #19:** Laser photon moles
- **PB 2023 #32, 33:** Radioactive decay

COMPETITION STRATEGY

Time Management (Critical!)

1. **First 5 min:** Scan ALL problems, mark easy ones
2. **Min 6-30:** Solve 3-4pt problems (build momentum)
3. **Min 31-60:** Attack 5-6pt problems
4. **Min 61-90:** Attempt 7-9pt if confident
5. **Last 30 min:** Hurry-up bonus (18:00-18:30 CET)

Never spend >10 min on one problem!

Numerical Techniques

When to go numerical:

- Cubic/quartic equations
- Transcendental equations ($\sin x = x/2$)
- Complex optimization

Tools allowed:

- WolframAlpha, Python, Mathematica
- GeoGebra (geometry problems!)
- Spreadsheets (iteration)

Trick: For $f(x) = 0$: Plot f and read zero crossings

Common Pitfalls

1. **Unit conversion errors** → Always convert to SI first
2. **Sign errors in vectors** → Draw coordinate system
3. **Forgetting small effects:**
   - Vapor pressure (PB 2024 #31)
   - Surface tension (PB 2024 #34)
   - Air buoyancy (PB 2024 #41)
4. **Reference frame confusion** → State frame explicitly
5. **Ignoring problem constraints** → Reread carefully

Answer Format

- **Sig figs:** Usually 3-4 (match problem precision)
- **Scientific notation:** Use for $|x| > 1000$ or < 0.01
- **Units:** Check required format (m/s vs km/h)
- **Negative signs:** Matter for vectors/directions

Trick: If answer seems wrong, check: (1) units, (2) signs, (3) arithmetic

Pre-Competition Prep

1 Week Before:

- Review this cheatsheet daily
- Solve 1-2 hard HRK problems per chapter
- Practice mental arithmetic
- Memorize key constants

1 Day Before:

- Solve last year's problems under time pressure
- Test your numerical tools (WolframAlpha, etc.)
- Print formula sheets
- Get good sleep!

Competition Day:

- Have water, snacks ready
- Clear desk except: calculator, pen, paper, this sheet
- Set timer for Hurry-up period (18:00 CET)
- Stay calm, you've prepared well!

KEY FORMULAS

Mechanics Essentials

$v^2 = v_0^2 + 2ax$
$x = x_0 + v_0 t + \frac{1}{2}at^2$
$F_{\text{net}} = ma$
$W = F \cdot d = \Delta KE$
$KE = \frac{1}{2}mv^2$
$U_g = mgh, \quad U_s = \frac{1}{2}kx^2$
$L = I\omega, \quad I_{\parallel} = I_{\text{cm}} + md^2$

Fluids & Thermo

$F_b = \rho_f V_{\text{disp}} g$
$p + \frac{1}{2}\rho v^2 + \rho g h = \text{const}$
$pV = nRT$
$Q = mc\Delta T$
$\Delta S = \int \frac{dQ}{T}$

E&M

$F = k\frac{q_1 q_2}{r^2}, \quad V = \frac{kq}{r}$
$V = IR, \quad P = IV = I^2R = \frac{V^2}{R}$
$\tau = RC$
$F = q(v \times B)$
$\mathcal{E} = -\frac{d\Phi_B}{dt}$

Waves & Modern

$v = f\lambda$
$f' = f\frac{v+v_o}{v-v_s}$ (approaching)
$\frac{1}{f} = \frac{1}{s_o} + \frac{1}{s_i}$
$E = hf = \frac{hc}{\lambda}$
$E^2 = (pc)^2 + (m_0c^2)^2$
$\gamma = \frac{1}{\sqrt{1-v^2/c^2}}$

Mathematical Tricks

Taylor: $e^x \approx 1 + x + \frac{x^2}{2}$ $(|x| \ll 1)$
Binomial: $(1+x)^n \approx 1 + nx$ $(|x| \ll 1)$
Small angle: $\sin\theta \approx \theta$, $\cos\theta \approx 1 - \frac{\theta^2}{2}$
Geometric series: $\sum_{n=0}^{\infty} r^n = \frac{1}{1-r}$ $(|r| < 1)$