

AP PHYSICS 1 STUDY GUIDE

176 High-Yield Concepts

Advanced Placement Course | College Board CED-aligned

- All 7 CED units: Kinematics to Torque & Rotational Motion
 - Core equations included with every concept
- Centripetal force, energy, momentum, SHM, torque & more
- Perfect for the AP Physics 1: Algebra-Based exam in May

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How to Use This Guide

This guide condenses the AP Physics 1: Algebra-Based course and exam description into high-yield concepts. It is not a textbook replacement -- it is the fastest way to review everything the exam covers and to target your weak units.

The AP Physics 1 exam is 90 minutes of 50 multiple-choice questions (45 single-select + 5 multi-select), then 90 minutes of 5 free-response questions. A four-function, scientific, or graphing calculator is allowed for the entire exam. No calculus is required -- every equation below is algebra-based.

How to use the concepts

- Each concept = term + concise explanation + high-yield exam tip (+ example where useful).
- First pass: read every concept in order. Underline anything unfamiliar.
- Second pass: focus only on the concepts you underlined.
- Two weeks before the exam: rapid-review every tip line (they are the highest-yield).
- Use the Table of Contents to jump straight to your weakest units.

Table of Contents

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Total: 176 high-yield concepts

How to use the TOC: work through the units in order on your first pass, then jump back to your weakest units for review. Each concept includes an Explanation, a high-yield exam tip, and where useful an Example. Mark the concepts you miss with a small dot in the margin and revisit them 48 hours later.

Unit 1: Kinematics

12-18% of the exam. Describing motion: position, velocity, acceleration, and graphs.

1 Position & Displacement

Explanation: Position is a vector from a reference point. Displacement (Δx) = final position - initial position (vector, has direction). Distance is the total path length (scalar).

AP Physics Tip: Displacement cares about start and end ONLY; distance cares about the path. A runner doing one lap has distance = track length but displacement = 0.

Example: A runner goes 100 m east then 100 m west: distance = 200 m, displacement = 0 m.

2 Speed vs Velocity

Explanation: Speed = distance/time (scalar, always positive). Velocity = displacement/time (vector, includes direction). Average velocity = $\Delta x / \Delta t$.

AP Physics Tip: Average velocity can be zero when displacement is zero, even with huge speed. Velocity tells you where and how fast; speed only how fast.

Example: Driving 60 mph around a circular track: speed constant 60 mph, velocity changes direction continuously.

3 Acceleration

Explanation: Acceleration = change in velocity / time (vector). Occurs when speed changes, direction changes, or both. Units: m/s^2 . Deceleration = acceleration opposite to motion (slowing).

AP Physics Tip: Acceleration is a change in VELOCITY (a vector) -- turning at constant speed is still acceleration (centripetal). Negative acceleration can mean speeding up in the negative direction.

Example: A car going from 0 to 27 m/s in 9 s accelerates at 3 m/s^2 . A car turning a corner at constant speed is accelerating.

4 Uniform Motion ($v = \text{constant}$)

Explanation: When velocity is constant, acceleration = 0 and position changes linearly: $x = x_0 + vt$. Graph: x vs t is a straight line (slope = velocity); v vs t is flat.

AP Physics Tip: Constant velocity = zero acceleration = straight-line x - t graph. The slope of x vs t is velocity.

Example: A car at steady 20 m/s for 10 s travels 200 m. Its x - t graph is a straight line with slope 20.

5 Uniform Acceleration Equations

Explanation: The big four (constant a): $v = v_0 + at$; $x = x_0 + v_0t + \frac{1}{2}at^2$; $v^2 = v_0^2 + 2a(x - x_0)$; $(x - x_0) = (v_0 + v)t/2$.

AP Physics Tip: Pick the equation with the variables you know and the one you need. List givens with signs (up positive or down positive -- be consistent).

Example: Drop a ball from rest: $v_0 = 0$, $a = g = 9.8 \text{ m/s}^2$. After 2 s: $v = 19.6 \text{ m/s}$, fallen $y = \frac{1}{2}(9.8)(4) = 19.6 \text{ m}$.

6 Free Fall

Explanation: Free fall: only gravity acts ($a = g = 9.8 \text{ m/s}^2$ downward). Object thrown up slows ($v = 0$ at top), then falls. Time up = time down (symmetry); speed at return = initial speed.

AP Physics Tip: At the highest point velocity is zero but acceleration is STILL g (9.8 m/s^2 down) -- never zero in free fall. Symmetry: total flight time = 2 x time to peak.

Example: Throw a ball up at 20 m/s: reaches peak in 2.04 s at 20.4 m, returns in 4.08 s at 20 m/s.

7 Projectile Motion

Explanation: Two independent components: horizontal (constant velocity, $a = 0$) and vertical (free fall, $a = -g$). Time of flight is set by the vertical motion. Range = $v_x \times \text{time}$.

AP Physics Tip: The horizontal and vertical motions are independent -- only time is shared. A projectile's path is parabolic (with air resistance neglected).

Example: A ball rolled off a table at 5 m/s and one dropped from rest hit the ground at the SAME time -- vertical motion decides the time.

8 Projectile Launched at an Angle

Explanation: Resolve initial velocity: $v_x = v \cos(\theta)$, $v_y = v \sin(\theta)$. Max height from $v_y = 0$. Range = $(v^2 \sin(2\theta))/g$ (max at 45 degrees, ignoring air resistance).

AP Physics Tip: 45 degrees gives max range (no air resistance). Complementary angles (30 and 60) give the same range. Time to peak = v_y/g .

Example: A ball launched at 20 m/s at 30 degrees: $v_x = 17.3$ m/s, $v_y = 10$ m/s; peak height = $10^2/(2 \times 9.8) = 5.1$ m; range = 35.3 m.

9 Position-Time Graphs

Explanation: Slope of x-t graph = velocity. Curving up = speeding up; curving down = slowing (for positive motion). Flat = at rest. Steep slope = fast.

AP Physics Tip: Read velocity from the SLOPE of x-t, not the position. Acceleration = curvature (concave up = increasing velocity).

Example: A parabolic x-t curve opening upward means velocity is increasing (acceleration positive).

10 Velocity-Time Graphs

Explanation: Slope of v-t graph = acceleration. Area under v-t graph = displacement (with sign). Flat line = constant velocity ($a = 0$).

AP Physics Tip: Area under v-t = displacement (count signs: above axis positive, below negative). Slope of v-t = acceleration. These two readings are tested constantly.

Example: A v-t graph that is a triangle from 0 to 10 s with peak 20 m/s has area = $1/2 \times 10 \times 20 = 100$ m displacement.

11 Acceleration-Time Graphs

Explanation: Area under a-t graph = change in velocity. Constant positive $a =$ v-t graph sloping up. Zero $a =$ flat v-t.

AP Physics Tip: Area under a-t = Δv . A constant $+2$ m/s² for 5 s gives $\Delta v = +10$ m/s.

Example: If a-t is a rectangle of height 3 m/s² and width 4 s, velocity increases by 12 m/s.

12 Relative Motion

Explanation: Velocities add as vectors in different reference frames: $v(\text{relative}) = v(\text{object}) - v(\text{frame})$. Classic: boat across a river, plane in wind.

AP Physics Tip: Velocity is relative to the frame. River current carries the boat sideways -- the boat's velocity relative to the shore = boat + current (vectors).

Example: A swimmer goes 2 m/s across a river flowing 1 m/s downstream: speed relative to shore = $\sqrt{2^2 + 1^2} = 2.24$ m/s, angled downstream.

13 Vector Components

Explanation: Any vector resolves into components: $A_x = A \cos(\theta)$, $A_y = A \sin(\theta)$. Add vectors by adding components. Magnitude = $\sqrt{A_x^2 + A_y^2}$; direction = $\arctan(A_y/A_x)$.

AP Physics Tip: Resolve into components to add vectors or to split projectile motion. Watch which angle you're given (from x-axis vs from vertical).

Example: A force of 10 N at 60 degrees above horizontal: $F_x = 10 \cos 60 = 5$ N, $F_y = 10 \sin 60 = 8.66$ N.

14 Graphical Vector Addition

Explanation: Tip-to-tail: place the tail of the next vector at the tip of the previous; the resultant runs from first tail to last tip. Parallelogram method works for two.

AP Physics Tip: The resultant vector closes the polygon. Order of addition doesn't matter (vector addition is commutative).

Example: Walking 3 m east then 4 m north: resultant = 5 m at 53 degrees north of east.

15 Scalars vs Vectors

Explanation: Scalars: magnitude only (mass, speed, distance, energy, time, temperature). Vectors: magnitude + direction (displacement, velocity, acceleration, force, momentum).

AP Physics Tip: AP Physics 1 asks directly: which is scalar/vector? Speed is scalar, velocity is vector; distance scalar, displacement vector.

Example: Mass (kg) and speed (m/s) are scalars. Force (N) and acceleration (m/s²) are vectors.

16 Instantaneous vs Average

Explanation: Average velocity = total displacement / total time. Instantaneous velocity = velocity at one instant (slope of tangent to x-t curve).

AP Physics Tip: *Instantaneous velocity is the limit of average as $\Delta t \rightarrow 0$ -- the tangent slope. On curved x-t graphs, use tangents for instantaneous, chords for average.*

Example: A car's speedometer reads instantaneous speed; total trip distance / time is average speed.

17 Kinematics with Constant Acceleration: Stopping Distance

Explanation: Stopping distance = $v^2/(2a)$ (from $v^2 = v_0^2 + 2ax$ with $v = 0$). Doubling speed quadruples stopping distance.

AP Physics Tip: *Stopping distance scales with speed SQUARED -- double speed, 4x distance. This is a classic qualitative question.*

Example: At 20 m/s with $a = -5 \text{ m/s}^2$: stopping distance = $400/10 = 40 \text{ m}$. At 40 m/s: 160 m (4x).

18 Frames of Reference

Explanation: Motion is described relative to a frame of reference. Different frames give different velocities for the same object but the same physical laws.

AP Physics Tip: *AP Physics 1: state the frame when describing motion. 'Relative to the ground' vs 'relative to the car' differ.*

Example: A ball dropped inside a moving train falls straight down in the train's frame but a parabola in the ground frame.

19 Displacement from Velocity Graphs

Explanation: Given a v-t graph, displacement = net area (positive above axis, negative below). Total distance = sum of absolute areas.

AP Physics Tip: *Net area = displacement; total absolute area = distance traveled. A v-t graph crossing zero means the object reversed direction.*

Example: V-t graph: +5 m/s for 4 s, then -5 m/s for 4 s: displacement = 0, distance = 40 m.

20 Motion Diagrams

Explanation: Motion diagrams show positions at equal time intervals. Increasing spacing = speeding up; decreasing = slowing; equal spacing = constant velocity; spacing changes = acceleration.

AP Physics Tip: *Spacing between dots reveals acceleration: getting farther apart = speeding up, closer = slowing, equal = constant v.*

Example: A strobe photo of a falling ball shows dots getting farther apart -- accelerating.

21 Kinematics Problem Strategy

Explanation: List knowns/unknowns (x, v_0 , v, a, t), choose the constant-acceleration equation containing all but one, solve, check units and signs.

AP Physics Tip: *Five variables, four equations -- you need three knowns to find one unknown. Set a consistent sign convention (up = + or down = +) and keep it.*

Example: Given v_0 , a, t, find x: use $x = v_0t + \frac{1}{2}at^2$. Given v_0 , v, a, find x: use $v^2 = v_0^2 + 2ax$.

22 Air Resistance vs Ideal Motion

Explanation: In ideal projectile/fall problems, air resistance is ignored. With air resistance, objects reach terminal velocity ($a \rightarrow 0$) and ranges shorten.

AP Physics Tip: *AP Physics 1 problems state 'neglect air resistance' unless told otherwise. Terminal velocity = drag balances gravity, net force = 0.*

Example: A skydiver falls faster and faster until drag = weight; then falls at constant terminal velocity ($a = 0$).

23 Two-Object Kinematics

Explanation: Two objects (dropped vs thrown, one chasing another) share time in some problems. Set up separate equations and equate the shared quantity (often time or position).

AP Physics Tip: *When objects meet, their positions are equal at the same time. Write each position as a function of time and set them equal.*

Example: A ball dropped from a roof and a ball thrown up from the ground meet when $y_1 = y_2$ at the same t.

Slope & Area Interpretation Summary

Explanation: For any graph: slope of position graph = velocity; slope of velocity graph = acceleration; area under velocity graph = displacement; area under acceleration graph = change in velocity.

AP Physics Tip: *The slope/area pairings are the core of AP Physics 1 graph questions. Memorize: x - t slope = v , v - t slope = a , v - t area = Δx , a - t area = Δv .*

Example: Given a v - t graph, both the slope (acceleration) and the area (displacement) can be extracted -- two different questions, one graph.

Kinematics Equation Checklist

Explanation: $v = v_0 + at$ (no x); $x = x_0 + v_0t + \frac{1}{2}at^2$ (no v); $v^2 = v_0^2 + 2a(x-x_0)$ (no t); $x-x_0 = (v_0+v)t/2$ (no a).

AP Physics Tip: *Each equation omits one variable -- pick the one omitting what you don't have and don't need.*

Example: If you have v_0 , v , a and want x , use $v^2 = v_0^2 + 2ax$ (omits t).

Unit 2: Dynamics

12-18% of the exam. Forces, Newton's laws, and applications.

26 Force & Newton's First Law

Explanation: A force is a push or pull (vector, N). Newton's first law: an object at rest stays at rest, and one in motion stays in motion at constant velocity, unless acted on by a net external force (inertia).

AP Physics Tip: First law = law of inertia: no net force $\rightarrow$ no acceleration. Inertia is mass (resistance to change in motion).

Example: A book stays on a table (forces balanced). A car passenger lurches forward when the car brakes -- inertia keeps them moving.

27 Newton's Second Law

Explanation: $F(\text{net}) = ma$. Net force causes acceleration proportional to force, inversely proportional to mass. Acceleration is in the same direction as net force. Units: $N = kg \ m/s^2$.

AP Physics Tip: $F = ma$ with NET force (vector sum). Always find the net force along the direction of motion. Same a means net force direction.

Example: A 2 kg object with net force 10 N accelerates at $5 \ m/s^2$. If force doubles (20 N), acceleration doubles to $10 \ m/s^2$.

28 Newton's Third Law

Explanation: For every action there is an equal and opposite reaction: forces come in pairs (same magnitude, opposite direction, on DIFFERENT objects).

AP Physics Tip: Action-reaction pairs act on different objects -- they never cancel each other (cancellation needs forces on the SAME object).

Example: The ground pushes you up with the same force you push down. A rocket pushes gas down; gas pushes rocket up.

29 Mass vs Weight

Explanation: Mass (kg) = amount of matter, constant everywhere. Weight (N) = mg , the gravitational force on the object -- varies with g . On the Moon, weight is $\sim 1/6$ but mass is the same.

AP Physics Tip: Weight = mg is a specific force, not the same as mass. An object's mass doesn't change with location; its weight does.

Example: A 60 kg astronaut: weight on Earth = 588 N, on the Moon = 98 N; mass = 60 kg in both places.

30 Free-Body Diagrams

Explanation: Draw the object alone, represent every force as an arrow from its center: weight (mg down), normal (perpendicular to surface), tension (along rope), friction (opposing motion), applied forces.

AP Physics Tip: AP Physics 1 requires FBDs in free response. Label every force; only include forces ON the object (not forces it exerts).

Example: A box on a floor: arrows for weight (down), normal (up), and any applied force or friction horizontally.

31 Normal Force

Explanation: The normal force (N) is the perpendicular contact force a surface exerts. On a flat surface with no vertical acceleration, $N = mg$. On an incline, $N = mg \cos(\theta)$. In an elevator, N changes with acceleration.

AP Physics Tip: Normal force is NOT always mg -- it adjusts to keep the object from penetrating the surface. In a rising elevator (a up), $N = m(g + a)$ (feels heavier).

Example: In an elevator accelerating upward at $2 \ m/s^2$, a 60 kg person feels $N = 60(9.8 + 2) = 708 \ N$ (heavier).

32 Tension

Explanation: Tension is the pulling force transmitted through a rope/string, directed along the rope away from the object. Ideal (massless, frictionless) ropes have constant tension throughout.

AP Physics Tip: Tension pulls TOWARD the rope. For a massless rope over a frictionless pulley, tension is the same on both sides.

Example: Two masses connected by a rope over a pulley: the rope transmits the same tension T to both masses.

33 Friction: Static & Kinetic

Explanation: Static friction (f_s) prevents motion: $f_s \leq \mu_s N$. Kinetic friction (f_k) opposes sliding: $f_k = \mu_k N$. $\mu_k < \mu_s$ typically. Friction is parallel to the surface, opposing relative motion.

AP Physics Tip: Static friction adjusts up to its maximum ($\mu_s N$); kinetic friction is constant at $\mu_k N$. Once moving, friction drops ($\mu_k < \mu_s$).

Example: Pushing a heavy box: static friction holds it until you exceed $\mu_s N$; then it slides with kinetic friction $\mu_k N$.

34 Friction on Inclines

Explanation: On an incline at angle θ : weight components are $mg \sin(\theta)$ (down the slope) and $mg \cos(\theta)$ (into the slope). $N = mg \cos(\theta)$. Friction opposes motion along the slope.

AP Physics Tip: Resolve weight into components parallel and perpendicular to the incline. At rest: $f_s = mg \sin(\theta)$. Sliding at constant velocity: $f_k = mg \sin(\theta)$.

Example: A box on a 30-degree incline: $mg \sin 30 = 0.5mg$ pulls it down the slope; $N = mg \cos 30$ balances the perpendicular component.

35 Inclined Plane Problems

Explanation: Set axes along and perpendicular to the incline. Along the slope: $F(\text{net}) = mg \sin(\theta) - f$. Perpendicular: $N = mg \cos(\theta)$. Acceleration = $g(\sin \theta - \mu \cos \theta)$ with friction.

AP Physics Tip: The incline geometry is the classic AP Physics 1 setup. Break gravity into components; the block accelerates down at $g \sin(\theta)$ when frictionless.

Example: A frictionless 30-degree incline: $a = g \sin 30 = 4.9 \text{ m/s}^2$ -- same for any mass. With $\mu_k = 0.2$: $a = 9.8(0.5 - 0.2 \times 0.866) = 3.2 \text{ m/s}^2$.

36 Elevator Problems

Explanation: In an accelerating elevator, apparent weight = normal force: $N = m(g + a)$ accelerating up; $N = m(g - a)$ accelerating down; $N = mg$ at constant velocity or at rest.

AP Physics Tip: Apparent weight changes only during ACCELERATION. Constant velocity (even fast) means $N = mg$. Free fall ($a = g$) means $N = 0$ (weightless).

Example: An elevator accelerating down at 3 m/s^2 : $N = m(9.8 - 3) = 6.8m$ N -- lighter. Accelerating up at 3 : $N = 12.8m$ N -- heavier.

37 Newton's Laws in Systems

Explanation: For connected objects, treat the whole system with $F = ma$ (external forces only), then isolate one object to find internal forces like tension.

AP Physics Tip: Two-body problems: system equation for acceleration, individual equations for tension. Tension is an internal force in the system view.

Example: Two blocks (3 kg + 2 kg) pulled by 25 N: $a = 25/5 = 5 \text{ m/s}^2$. Tension pulling the 2 kg block = $2 \times 5 = 10 \text{ N}$.

38 Atwood Machine

Explanation: Two masses over a frictionless pulley: $a = (m_1 - m_2)g/(m_1 + m_2)$. Heavier mass accelerates down, lighter up. Tension = $2m_1m_2 g/(m_1 + m_2)$.

AP Physics Tip: The Atwood machine acceleration formula is $(m_1 - m_2)g/(m_1 + m_2)$. If masses are equal, $a = 0$ and $T = mg$.

Example: $m_1 = 5 \text{ kg}$, $m_2 = 3 \text{ kg}$: $a = (5-3)9.8/8 = 2.45 \text{ m/s}^2$. $T = 2(5)(3)(9.8)/8 = 36.75 \text{ N}$.

39 Apparent Weight & Normal Force Context

Explanation: Scale readings measure the normal force. Any vertical acceleration changes the reading. In an elevator, the scale shows N , not mg , whenever accelerating.

AP Physics Tip: A bathroom scale reads N . Accelerating up $\rightarrow$ reads more; accelerating down $\rightarrow$ reads less; free fall $\rightarrow$ reads zero.

Example: Standing on a scale in a downward-accelerating elevator: reading = $m(g - a) < mg$.

40 Action-Reaction Pairs in Practice

Explanation: Common pairs: book-weight/table-push, rocket/gas, person/ground (walking), hand/rope (tension), Earth/object (gravity). Identify the other object for the reaction.

AP Physics Tip: To find a reaction force, ask: the force is ON this object BY what? The reaction is on THAT object by this one -- equal and opposite.

Example: The weight of a ball (Earth on ball) pairs with the ball's gravitational pull on Earth (same magnitude, opposite direction).

41 Drag & Terminal Velocity

Explanation: Drag force increases with speed (and with fluid density/cross-section). Terminal velocity: drag = weight, net force = 0, constant velocity. Qualitatively: terminal v higher for denser/heavier, lower for larger area.

AP Physics Tip: *Terminal velocity occurs when drag balances weight -- acceleration becomes zero, NOT speed zero. Heavier objects fall faster at terminal velocity (higher terminal v).*

Example: A skydiver reaches terminal velocity when drag = mg ; spreading arms increases area and drag, lowering terminal velocity.

42 Springs: Hooke's Law

Explanation: $F(\text{spring}) = -kx$: the force a spring exerts is proportional to displacement from equilibrium and opposite in direction. k = spring constant (N/m). Spring force is a restoring force.

AP Physics Tip: *The minus sign means restoring (opposes displacement). Hooke's law applies within the elastic limit. $F = kx$ is also the force YOU apply to stretch it.*

Example: Stretching a spring ($k = 200 \text{ N/m}$) by 0.1 m requires $F = 200 \times 0.1 = 20 \text{ N}$. The spring pulls back with 20 N .

43 Spring Scales & Hanging Masses

Explanation: A hanging mass on a spring scale reads the tension. At rest: $T = mg$, scale reads weight. Accelerating up: $T = m(g + a)$.

AP Physics Tip: *Spring scale reads tension -- same logic as elevator problems. Hanging mass at rest = mg .*

Example: A 2 kg mass hangs on a scale at rest: reads 19.6 N . If the scale is pulled up at 2 m/s^2 , it reads $2(11.8) = 23.6 \text{ N}$.

44 Force Components & Equilibrium

Explanation: Equilibrium: net force = 0, so sum of x -components = 0 and sum of y -components = 0. Solve for unknowns (tensions, normal forces, applied forces).

AP Physics Tip: *In equilibrium, break all forces into x and y and set each sum to zero. This is the standard hanging-sign problem setup.*

Example: A sign hangs from two ropes at 30 and 60 degrees: $T_1 \sin 30 + T_2 \sin 60 = mg$ and $T_1 \cos 30 = T_2 \cos 60$ solve for T_1, T_2 .

45 Pulleys & Ropes

Explanation: Ideal pulleys redirect tension without changing its magnitude (frictionless, massless). Fixed pulleys change direction; movable pulleys provide mechanical advantage.

AP Physics Tip: *An ideal pulley doesn't change tension -- only direction. Systems with multiple pulleys can halve the required force (mechanical advantage).*

Example: Lifting with a single fixed pulley: you pull down with $T = mg$; the pulley just changes direction.

46 Net Force & Acceleration Direction

Explanation: The acceleration is always in the direction of the NET force. If an object speeds up, net force points along velocity; if it slows, net force opposes velocity; circular motion, net force points to center.

AP Physics Tip: *Net force and acceleration are always in the same direction. Use this to sanity-check FBDs: the arrow of net force matches the direction of a .*

Example: A car slowing down has net force opposite its velocity. A car turning left has net force pointing left (toward the center).

47 Ramps, Strings, and Connected Systems

Explanation: Combine all the tools: incline + pulley + friction. Write Newton's second law for each object along its own axis, then solve the system.

AP Physics Tip: *Set up one equation per object, aligned with that object's motion. The tension is shared (same rope), acceleration magnitude is shared.*

Example: Block on a ramp (m_1) attached by a rope over a pulley to hanging mass (m_2): $m_2g - T = m_2a$ and $T - m_1g \sin \theta - f = m_1a$.

48 Contact Forces Between Objects

Explanation: When objects push each other (stacked or in a line), the contact force between them is found by isolating one object. The contact force is NOT the applied force unless the other object is massless.

AP Physics Tip: *Two blocks pushed by F : contact force on the rear block = $m(\text{rear}) \times a$. Internal contact forces are equal and opposite (3rd law).*

Example: A 30 N force pushes $2 \text{ kg} + 3 \text{ kg}$ blocks: $a = 6 \text{ m/s}^2$; the force the 3 kg block exerts on the 2 kg block = $2 \times 6 = 12 \text{ N}$.

49 Friction Direction & Relative Motion

Explanation: Kinetic friction opposes RELATIVE sliding between surfaces. Static friction opposes the tendency to slip. On a moving conveyor, friction can point in the direction of motion (it's what accelerates the object).

AP Physics Tip: *Friction isn't always 'backward' -- it's whatever opposes relative motion. A car accelerates because static friction pushes it FORWARD.*

Example: A crate on an accelerating truck: static friction points forward, accelerating the crate with the truck. When the truck brakes, friction flips backward.

50 Dynamics Problem-Solving Flow

Explanation: 1) Draw FBD. 2) Choose axes. 3) Break forces into components. 4) Write $F(\text{net}) = ma$ along each axis. 5) Solve. 6) Check: does the answer make physical sense?

AP Physics Tip: *Systematic FBD-first approach earns most of the points on AP free response. Always write equations symbolically before plugging numbers.*

Example: For any dynamics problem: identify the object, all forces on it, then $F(\text{net}) = ma$ along the direction of motion.

51 Newton's Laws: Limitations & Scope

Explanation: Newton's laws apply to inertial (non-accelerating) reference frames and speeds much less than light. In accelerating frames, fictitious forces (centrifugal) appear.

AP Physics Tip: *AP Physics 1 sticks to inertial frames for Newton's laws. The 'centrifugal force' you feel in a turning car is a fictitious force from a rotating frame.*

Example: In a car turning left, you feel pushed right (centrifugal) -- a fictitious force; the real force is friction acting toward the center.

Unit 3: Circular Motion & Gravitation

12-18% of the exam. Uniform circular motion, centripetal force, and gravitational interactions.

52 Uniform Circular Motion

Explanation: Motion at constant speed along a circle. Velocity is tangent to the circle (direction changes constantly), so there IS acceleration: centripetal, pointing to the center.

AP Physics Tip: *Constant SPEED but not constant velocity -- direction changes, so acceleration is nonzero and points to the center.*

Example: A satellite orbits at constant speed; its velocity direction changes continuously, so it accelerates toward Earth's center.

53 Centripetal Acceleration

Explanation: $a(c) = v^2/r = \omega^2 r$. Always points toward the center of the circle. For a given speed, smaller radius = larger centripetal acceleration.

AP Physics Tip: *$a = v^2/r$ is the key formula. Sharp turns (small r) at high speed need huge centripetal acceleration.*

Example: A car at 20 m/s on a 100 m radius curve: $a = 400/100 = 4 \text{ m/s}^2$ toward the center.

54 Centripetal Force

Explanation: $F(c) = mv^2/r = m \omega^2 r$. The NET force toward the center causes circular motion. It is not a new force -- it's provided by tension, gravity, friction, normal force, etc.

AP Physics Tip: *Identify WHAT provides the centripetal force (tension? friction? gravity?) and set that equal to mv^2/r .*

Example: A ball on a string: tension provides $F(c)$. A car turning: static friction provides $F(c)$. A satellite: gravity provides $F(c)$.

55 Angular Quantities

Explanation: Angular position θ (radians), angular velocity $\omega = \Delta \theta / \Delta t$ (rad/s), angular acceleration α . Conversion: $v = \omega r$ at the rim.

AP Physics Tip: *One full revolution = 2π radians. $v = \omega r$ relates linear speed at the rim to angular speed. Radians are unitless but essential.*

Example: A wheel at 10 rad/s with radius 0.5 m has rim speed $v = 10 \times 0.5 = 5 \text{ m/s}$. One revolution ($2\pi \text{ rad}$) takes 0.628 s.

56 Period & Frequency

Explanation: Period T = time per revolution; frequency f = revolutions per second (Hz). $T = 1/f$. Orbital speed $v = 2\pi r/T$. Angular speed $\omega = 2\pi/T = 2\pi f$.

AP Physics Tip: *$v = 2\pi r/T$ and $\omega = 2\pi/T$ are the connection between motion and timing. Keep T in seconds.*

Example: A Ferris wheel completes a turn in 30 s: $T = 30 \text{ s}$, $f = 1/30 \text{ Hz}$, $\omega = 2\pi/30 = 0.21 \text{ rad/s}$.

57 Vertical Circles

Explanation: In vertical circular motion, speed and tension change: at the top, $T + mg = mv^2/r$; at the bottom, $T - mg = mv^2/r$. Minimum speed at top: $v = \sqrt{gr}$ ($T = 0$).

AP Physics Tip: *At the top of a vertical loop, gravity HELPS provide centripetal force ($T + mg$). Minimum top speed: $\sqrt{gr}$ -- below that, the ball falls.*

Example: A bucket swung in a vertical circle of radius 1 m: minimum top speed = $\sqrt{9.8} = 3.13 \text{ m/s}$ keeps water in.

58 Banked Curves

Explanation: Banking uses the normal force's horizontal component to provide centripetal force. Ideal bank angle: $\tan(\theta) = v^2/(rg)$ (no friction needed).

AP Physics Tip: *For ideal banking, $\tan \theta = v^2/(rg)$. Friction is unnecessary at that speed; the horizontal component of N does the job.*

Example: A curve of radius 100 m banked for 25 m/s: $\tan \theta = 625/(100 \times 9.8) = 0.638$, $\theta = 32.5 \text{ degrees}$.

59 Conical Pendulum

Explanation: A mass on a string moving in a horizontal circle: vertical component of tension balances weight ($T \cos \theta = mg$); horizontal component provides centripetal force ($T \sin \theta = mv^2/r$).

AP Physics Tip: Break tension into components: vertical balances mg , horizontal provides mv^2/r . The angle sets the speed.

Example: For a conical pendulum, $\tan \theta = v^2/(rg)$ -- same relationship as banking.

60 Gravitational Force

Explanation: Newton's law of gravitation: $F = Gm_1m_2/r^2$, $G = 6.67 \times 10^{-11} \text{ N m}^2/\text{kg}^2$. Force is attractive, along the line joining centers, proportional to product of masses, inverse square of distance.

AP Physics Tip: $F = Gm_1m_2/r^2$ -- inverse SQUARE law. Doubling distance quarters the force. Doubling one mass doubles the force.

Example: Two 1000 kg masses 1 m apart: $F = (6.67 \times 10^{-11})(1000)(1000)/1 = 6.67 \times 10^{-5} \text{ N}$ -- tiny. At 2 m: $1.67 \times 10^{-5} \text{ N}$ (quarter).

61 Gravitational Field

Explanation: The gravitational field $g = F/m = GM/r^2$ at distance r from mass M . Near Earth's surface, $g = 9.8 \text{ m/s}^2$. g decreases with altitude: $g = GM/(R + h)^2$.

AP Physics Tip: $g = GM/r^2$ is the field at any distance. At Earth's surface, plug $R(\text{Earth})$: $g = 9.8$. At 2 Earth radii from center, $g = 2.45 \text{ m/s}^2$.

Example: At altitude equal to Earth's radius ($r = 2R$), $g = 9.8/4 = 2.45 \text{ m/s}^2$ -- an object weighs a quarter of its surface weight.

62 Inverse-Square Law Reasoning

Explanation: If distance triples, gravitational force drops by 9x. If mass doubles, force doubles. Combine effects: force scales as $m_1 \times m_2 / r^2$.

AP Physics Tip: Use ratios: $F_2/F_1 = (m_2'/m_1') \times (r_1/r_2)^2$. Ratio problems avoid messy constants.

Example: Distance doubles and one mass triples: force changes by $3/4 = 0.75 \times (3 / 2^2)$.

63 Orbits & Orbital Speed

Explanation: For a circular orbit, gravity provides centripetal force: $GMm/r^2 = mv^2/r \rightarrow v = \sqrt{GM/r}$. Orbital speed decreases with larger orbit radius.

AP Physics Tip: Orbital speed $v = \sqrt{GM/r}$: bigger orbit, slower speed (but longer period). The mass of the SATELLITE cancels.

Example: Low Earth orbit ($r \sim 6.8 \times 10^6 \text{ m}$): $v = \sqrt{(6.67 \times 10^{-11} \times 5.97 \times 10^{24}) / 6.8 \times 10^6} = 7,650 \text{ m/s}$.

64 Kepler's Laws

Explanation: 1) Planets move in ellipses with the Sun at a focus. 2) Equal areas in equal times (planets move faster near the Sun). 3) T^2 proportional to a^3 (T^2/a^3 constant for the system).

AP Physics Tip: Kepler's third law: T^2 proportional to r^3 for circular orbits around the same central mass. Near perihelion, faster; near aphelion, slower.

Example: If planet B orbits at 4x the radius of planet A, its period is $\sqrt{4^3} = 8 \times$ longer.

65 Satellites & Weightlessness

Explanation: Satellites in orbit are in free fall -- they continuously fall toward Earth but move sideways fast enough to keep missing it. 'Weightless' means apparent weight = 0 ($N = 0$), not zero gravity.

AP Physics Tip: Astronauts are weightless because they're in free fall, NOT because gravity is absent -- gravity is ~90% as strong in low orbit.

Example: The ISS astronauts float because the station (and they) fall around Earth at the same rate -- no normal force.

66 Geosynchronous Orbits

Explanation: A geosynchronous orbit has $T = 24 \text{ h}$ (matching Earth's rotation), so the satellite stays above the same longitude. Only possible at one altitude (~35,800 km) above the equator for geostationary.

AP Physics Tip: Geostationary: $T = 86,400 \text{ s}$, always above the equator. Use Kepler/Newton to find r : $GMm/r^2 = m(2\pi/T)^2 r$.

Example: Communications satellites sit at ~35,800 km altitude so dishes don't need to track them.

67 Gravitational Potential Energy

Explanation: $U(g) = -GMm/r$ (defined zero at infinite separation, negative for bound systems). Near Earth's surface: $\Delta U = m g \Delta h$ (approximation for small heights).

AP Physics Tip: $U = -GMm/r$ is **NEGATIVE** for bound orbits. The minus sign means energy is required to separate the masses. $\Delta U = m g \Delta h$ only near the surface.

Example: To move a satellite from r_1 to r_2 (farther), $\Delta U = -GMm/r_2 - (-GMm/r_1) > 0$ -- energy must be added.

68 Escape Velocity

Explanation: Escape speed = $\sqrt{2GM/r}$: the speed needed to reach infinity with zero remaining kinetic energy ($KE + U = 0$). Independent of the object's mass.

AP Physics Tip: $v_{esc} = \sqrt{2GM/r} = \sqrt{2} \times \text{orbital speed}$. Earth: 11.2 km/s. If $KE + U \geq 0$, the object escapes.

Example: From Earth's surface, escape speed is 11.2 km/s; rockets must reach this (or use staging/gravity assists) to leave Earth.

69 Energy in Circular Orbits

Explanation: For a circular orbit: $KE = GMm/(2r)$, $U = -GMm/r$, total $E = -GMm/(2r)$. Total energy is negative (bound) and half the (negative) potential energy.

AP Physics Tip: Total orbital energy $E = -GMm/2r$: bigger orbit = higher (less negative) energy. To boost a satellite to a higher orbit, add energy.

Example: $E(\text{orbit}) = KE + U = GMm/2r - GMm/r = -GMm/2r$. Moving to higher r increases E (less negative).

70 Orbit Changes & Transfers

Explanation: To move to a higher circular orbit, increase speed (elliptical transfer), then increase again at apogee to circularize. Energy must increase at each burn.

AP Physics Tip: Raising an orbit requires **TWO** burns (Hohmann transfer): speed up at low orbit, speed up again at high orbit. Firing retrograde lowers the orbit.

Example: The ISS boosts itself periodically: firing forward raises the orbit slightly; drag slowly decays it.

71 Centripetal Force Provided by...

Explanation: Common providers: tension (ball on string), static friction (car turning), normal force (banked curve, loop top/bottom), gravity (satellites), magnetic/electric (charged particles).

AP Physics Tip: For each circular-motion scenario, first ask: **WHAT** supplies the inward force? Set that expression = mv^2/r .

Example: A car turning on flat road: static friction = mv^2/r . An electron in an atom: electric attraction = mv^2/r .

72 Rotating Frames & Fictitious Forces

Explanation: In a rotating reference frame, objects appear pushed outward by 'centrifugal force' (fictitious). The real force is inward (centripetal). AP Physics 1 uses inertial frames.

AP Physics Tip: The outward feeling when turning is inertia (you keep going straight) -- not a real outward force. Real forces point toward the center.

Example: In a car turning left, you slide right in your seat: no force pushes you right; you continue straight while the car turns under you.

73 Circular Motion & Friction

Explanation: Maximum speed on a flat curve: friction provides $F(c)$: $\mu_s mg = mv^2/r \rightarrow v(\text{max}) = \sqrt{\mu_s g r}$. Wet roads (low μ) mean lower safe speeds.

AP Physics Tip: $v(\text{max}) = \sqrt{\mu_s g r}$ on a flat curve. The mass cancels -- heavier cars don't corner faster on the same tires.

Example: $\mu_s = 0.8$, $r = 50$ m: $v(\text{max}) = \sqrt{0.8 \times 9.8 \times 50} = 19.8$ m/s. With $\mu = 0.2$ (ice): 9.9 m/s.

74 Circular Motion Problem Strategy

Explanation: 1) Draw FBD. 2) Identify the center direction. 3) Set the radial net force = mv^2/r (toward center positive). 4) Any perpendicular direction: $F(\text{net}) = 0$. 5) Solve.

AP Physics Tip: Radial direction: $F(\text{net, toward center}) = mv^2/r$. This works for every circular motion problem -- vertical loops, banked curves, satellites.

Example: At the bottom of a loop: $N - mg = mv^2/r$, so $N = mg + mv^2/r$ (greater than mg -- 'heavy'). At the top: $N + mg = mv^2/r$.

75 Radians & Arc Length

Explanation: Angles in radians: arc length $s = r \theta$ (θ in radians). One full circle = 2π radians = 360 degrees. Convert: rad = degrees $\times \pi/180$.

AP Physics Tip: Always convert degrees to radians for $\omega = \theta/t$ and $s = r \theta$. 180 degrees = π rad; 90 = $\pi/2$; 60 = $\pi/3$.

Example: A wheel of radius 0.4 m turns 90 degrees ($\pi/2$ rad): arc length $s = 0.4 \times \pi/2 = 0.628$ m.

76 Nonuniform Circular Motion

Explanation: When speed changes along a circular path, acceleration has TWO components: centripetal (v^2/r , toward center) and tangential ($a(t) = dv/dt$, along the path). Net acceleration is the vector sum.

AP Physics Tip: Nonuniform circular motion: radial component = v^2/r , tangential component = rate of speed change. $F(\text{tangential}) = ma(t)$ changes speed; $F(\text{radial}) = mv^2/r$ changes direction.

Example: A car speeding up around a curve has both inward acceleration (v^2/r) and forward acceleration. A pendulum at the bottom has both centripetal and (changing) tangential components.

Unit 4: Energy

12-18% of the exam. Work, kinetic/potential energy, conservation, and power.

77 Work

Explanation: Work = $F d \cos(\theta)$: force times displacement times cosine of the angle between them. Units: joules ($J = N \cdot m$). Work is a scalar. Positive work adds energy; negative removes it.

AP Physics Tip: Only the force component ALONG the displacement does work ($F \cos \theta$). Force perpendicular to motion (centripetal, normal on flat) does zero work.

Example: Lifting a 10 kg box 2 m: $W = mg \times d = 98 \times 2 = 196 \text{ J}$. Pushing a wall that doesn't move: $W = 0$.

78 Work by Constant Force

Explanation: For constant force along motion: $W = F d$. Friction always does negative work (opposes motion). Gravity does positive work falling, negative rising.

AP Physics Tip: Work by friction = $-f d$ (always negative along the sliding direction). Work by gravity = $-mg \Delta h$ (rising) or $+mg \Delta h$ (falling).

Example: Sliding a 50 N box 5 m against 20 N friction: work by you = 250 J, work by friction = -100 J, net work = 150 J.

79 Work-Energy Theorem

Explanation: $W(\text{net}) = \Delta KE = KE(f) - KE(i)$. The net work done on an object equals its change in kinetic energy. Applies to any net force.

AP Physics Tip: $W(\text{net}) = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$. If net work is positive, the object speeds up; negative, slows. Zero net work, no KE change.

Example: A car (1000 kg) goes from 10 to 20 m/s: $\Delta KE = \frac{1}{2}(1000)(400 - 100) = 150,000 \text{ J}$ of net work.

80 Kinetic Energy

Explanation: $KE = \frac{1}{2}mv^2$. Energy of motion, scalar, always positive (or zero). Doubling speed quadruples KE (v is squared).

AP Physics Tip: KE scales with v^2 : 2x speed = 4x KE, 3x speed = 9x KE. Braking distance follows from this.

Example: A 2 kg object at 3 m/s: $KE = \frac{1}{2}(2)(9) = 9 \text{ J}$. At 6 m/s: 36 J (4x).

81 Gravitational Potential Energy

Explanation: $U(g) = mgh$ near Earth's surface. Energy stored by height in a gravitational field. Reference level is arbitrary -- only CHANGES in U matter.

AP Physics Tip: $\Delta U = mg \Delta h$; pick a zero level and be consistent. U is positive above the reference, negative below.

Example: A 5 kg box 3 m above the floor: $U = 5 \times 9.8 \times 3 = 147 \text{ J}$ relative to the floor (choose floor as zero).

82 Elastic Potential Energy

Explanation: $U(s) = \frac{1}{2}kx^2$ for a spring stretched/compressed x from equilibrium. Energy is stored in the deformed spring. Always positive (x squared).

AP Physics Tip: $U(s) = \frac{1}{2}kx^2$. Compressed and stretched the same distance store the same energy. At $x = 0$ (equilibrium), $U = 0$.

Example: A spring ($k = 400 \text{ N/m}$) compressed 0.1 m stores $U = \frac{1}{2}(400)(0.01) = 2 \text{ J}$.

83 Mechanical Energy Conservation

Explanation: If only conservative forces act (gravity, springs), total mechanical energy is conserved: $KE + U = \text{constant}$. Nonconservative forces (friction, drag) change mechanical energy.

AP Physics Tip: $E(\text{mech}) = KE + U(g) + U(s)$ is constant with no friction. Energy transforms between forms but total is conserved.

Example: A ball dropped from height h reaches the ground with $v = \sqrt{2gh}$: $mgh = \frac{1}{2}mv^2$. From 5 m: $v = \sqrt{98} = 9.9 \text{ m/s}$.

84 Conservative vs Nonconservative Forces

Explanation: Conservative (gravity, springs, electric): work is path-independent, energy stored as potential, fully recoverable. Nonconservative (friction, drag, tension with dissipation): work depends on path, mechanical energy is lost as heat.

AP Physics Tip: Conservative forces have potential energy; nonconservative forces convert mechanical energy to thermal/other forms. Friction is the classic nonconservative force.

Example: Sliding a box up a ramp vs lifting it straight up: gravity does the same work either path; friction's work depends on path length.

85 Energy with Friction

Explanation: With friction: $W(\text{friction}) = \Delta KE + \Delta U$ (work by friction = change in mechanical energy, negative). $E(\text{mech, final}) = E(\text{mech, initial}) - f d$.

AP Physics Tip: Friction removes energy: $E(f) = E(i) - f d$. Solve by tracking total mechanical energy before/after and subtracting friction's work.

Example: A 2 kg block slides 3 m on a surface ($\mu_k = 0.3$): friction removes $f d = (0.3 \times 2 \times 9.8) \times 3 = 17.6 \text{ J}$ from its mechanical energy.

86 Power

Explanation: Power = work/time = $\Delta E/\text{time}$. Units: watts ($W = \text{J/s}$). Also $P = F v$ for constant force along motion. Horsepower: 1 hp = 746 W.

AP Physics Tip: $P = W/t = F v$. A car's engine power relates to force $\times$ speed; going uphill at constant speed requires power = $mg \sin(\theta) \times v$.

Example: Lifting 100 kg 2 m in 2 s: $W = 1,960 \text{ J}$, $P = 980 \text{ W}$. A 1000 kg car at 30 m/s with 3000 N drive force: $P = 90,000 \text{ W}$.

87 Energy Bar Charts & Diagrams

Explanation: Bar charts track KE, U_g , U_s , and work by nonconservative forces. Total height of bars changes only when nonconservative work occurs.

AP Physics Tip: Draw the initial and final bar charts: KE and U convert between forms; a friction bar accounts for lost mechanical energy. This is an AP free-response skill.

Example: Roller coaster from rest at top: initial bar is all U_g ; at the bottom it's all KE (heights equal, no friction).

88 Pendulum Energy

Explanation: A pendulum converts $U(g)$ (at the ends) to KE (at the bottom) and back. Speed is max at the bottom: $v = \sqrt{2gL(1 - \cos \theta)}$ for release angle θ . Total energy constant (no friction).

AP Physics Tip: At the lowest point, all energy is kinetic (if released from rest at the extreme). At the extremes, all energy is potential.

Example: A pendulum released from height h above its lowest point reaches $v = \sqrt{2gh}$ at the bottom -- same as free fall from h .

89 Spring Energy Conversions

Explanation: A mass on a spring converts $U(s)$ to KE and back: $\frac{1}{2}kx^2 = \frac{1}{2}mv^2$ at equilibrium passage. Max speed at equilibrium; max spring energy at full compression/stretch.

AP Physics Tip: At maximum displacement: all $U(s)$, no KE ($v = 0$). At equilibrium: all KE (max speed), no $U(s)$. $v(\text{max}) = \sqrt{k/m} \times A$.

Example: Mass 0.5 kg on spring ($k = 200 \text{ N/m}$) pulled 0.1 m: $v(\text{max}) = \sqrt{200/0.5} \times 0.1 = 2 \text{ m/s}$ at equilibrium.

90 Energy vs Momentum

Explanation: Energy is a scalar conserved when no external work/heat; momentum is a vector conserved when no external force. In collisions, momentum is always conserved (isolated), KE only sometimes.

AP Physics Tip: Momentum conservation applies to ALL isolated collisions; KE conservation only to elastic ones. Use energy for height/speed problems, momentum for collisions.

Example: Two carts colliding: momentum conserved always; KE conserved only for elastic (bouncy) collisions.

91 Work Done by Gravity & Conservative Paths

Explanation: Work by gravity depends only on height change: $W(g) = -mg \Delta h$, regardless of path. Going up a ramp vs stairs vs elevator: same work by gravity for the same height gain.

AP Physics Tip: Gravity's work = $-mg \Delta h$, path-independent (that's what makes it conservative). Use height change, not distance traveled.

Example: Carrying a box up 10 flights (30 m) via stairs or elevator: gravity does the same $-mg(30)$ work either way.

92 Springs in Series & Parallel

Explanation: Parallel springs: $k(\text{eff}) = k_1 + k_2$ (stiffer). Series springs: $1/k(\text{eff}) = 1/k_1 + 1/k_2$ (softer). AP Physics 1 tests this conceptually.

AP Physics Tip: Parallel springs add stiffness (both stretch the same). Series springs are softer (each stretches partially).

Example: Two 100 N/m springs parallel: $k(\text{eff}) = 200 \text{ N/m}$. In series: $k(\text{eff}) = 50 \text{ N/m}$.

93 Power & Efficiency

Explanation: Efficiency = useful output energy / input energy (or power). Machines never exceed 100% (energy lost to friction, heat).

AP Physics Tip: *Efficiency = $E(\text{out})/E(\text{in}) \times 100\%$. Losses go to thermal energy (friction). Simple machines trade force for distance, not energy.*

Example: A motor that inputs 500 J and outputs 400 J of work is 80% efficient; 100 J became heat.

94 Energy in Collisions (Overview)

Explanation: Elastic collision: KE conserved (billiard balls, atomic scattering). Inelastic: KE lost (sticking together). Perfectly inelastic: objects stick, max KE loss. Momentum conserved in ALL.

AP Physics Tip: *Elastic = KE conserved + momentum. Perfectly inelastic = stick together, KE minimized. In any collision, momentum is conserved (isolated system).*

Example: Two identical carts, one moving hits one at rest and they stick: final speed = half the initial (momentum conservation).

95 Work by Variable Force

Explanation: Work by a variable force = area under the F vs x graph. Springs ($F = kx$): $W = 1/2 kx^2$ = triangle area on the F-x graph.

AP Physics Tip: *Area under F-x = work. For a spring, the F-x graph is a triangle: $W = 1/2 (kx)(x) = 1/2 kx^2$.*

Example: A force rises linearly 0 to 10 N over 2 m: work = $1/2(10)(2) = 10$ J (triangle area).

96 Potential Energy Curves & Stability

Explanation: On a $U(x)$ curve, equilibrium points are where the curve is flat ($F = -dU/dx = 0$). Stable equilibrium: bottom of a valley (U minimum). Unstable: top of a hill (U maximum).

AP Physics Tip: *Force = -slope of the $U(x)$ graph. At a minimum of U , equilibrium is stable (small displacement returns); at a maximum, unstable.*

Example: A ball in a bowl: U minimum at the bottom -- stable (returns if nudged). A ball on a hilltop: U maximum -- unstable (rolls off).

97 Energy Diagrams for Springs

Explanation: For a mass on a spring, total energy E is a horizontal line; $KE = E - U(s)$ is the gap between E and the parabola $1/2 kx^2$. Turning points where $KE = 0$ ($U = E$).

AP Physics Tip: *On an energy diagram, KE is the vertical gap between total energy and the potential curve. Turning points occur where $KE = 0$.*

Example: If total $E = 2$ J and $U(s)$ at some $x = 1.5$ J, then $KE = 0.5$ J there.

98 Energy Problem Strategy

Explanation: 1) Choose initial and final states. 2) List KE , U_g , U_s at each. 3) Apply $E(i) + W(\text{nonconservative}) = E(f)$. 4) Solve for the unknown. 5) Check units (joules) and reasonableness.

AP Physics Tip: *Write $E(i) + W(nc) = E(f)$ explicitly. Friction contributes negative $W(nc)$. This single equation handles most AP energy problems.*

Example: A block slides down a rough ramp: $mgh + 0 = 1/2 mv^2 + 0 - f d \dots$ rearrange: $mgh - fd = 1/2 mv^2$.

99 Spring Launch Problems

Explanation: A compressed spring launches a block: $1/2 kx^2 = 1/2 mv^2$ (+ work against friction if present). Launch speed $v = \sqrt{kx^2/m}$ for a frictionless horizontal launch.

AP Physics Tip: *The spring's stored energy becomes the block's KE : $1/2 kx^2 = 1/2 mv^2$. Include friction work when the surface is rough.*

Example: A spring ($k = 500$ N/m) compressed 0.2 m launches a 2 kg block: $v = \sqrt{500 \times 0.04/2} = \sqrt{10} = 3.16$ m/s.

100 Combined Potential Energies

Explanation: When gravity AND springs act, total mechanical energy includes both: $E = 1/2 mv^2 + mgh + 1/2 kx^2$. Track all three forms between initial and final states.

AP Physics Tip: *Write every energy term present: KE , U_g (heights), U_s (springs). A mass on a spring at a height has both U_g and U_s .*

Example: A 1 kg block compresses a spring 0.1 m ($k = 200$) at ground level, then launches to height h : $1/2(200)(0.01) = mgh \rightarrow h = 0.1$ m.

Explanation: Power to lift at constant speed: $P = W/t = mgh/t = mg v(\text{vertical})$. Climbing stairs, elevators, and cranes are all $P = mgh/t$ problems.

AP Physics Tip: $P = mgh/t$ for lifting. $P = Fv$ for constant force and speed. Compare power outputs by work over time.

Example: A 70 kg person climbs 3 m in 5 s: $P = 70 \times 9.8 \times 3 / 5 = 412 \text{ W}$. An elevator lifting 500 kg 10 m in 20 s: $P = 500 \times 9.8 \times 10/20 = 2,450 \text{ W}$.

Unit 5: Momentum

12-18% of the exam. Impulse, momentum conservation, and collisions.

102 Momentum

Explanation: Momentum $p = mv$ (vector, kg m/s). Direction matches velocity. A heavier or faster object has more momentum. Momentum is a vector -- components matter.

AP Physics Tip: $p = mv$ with direction. Two objects can have the same KE but different momentum (and vice versa). Momentum is conserved in isolated systems.

Example: A 1000 kg car at 20 m/s: $p = 20,000$ kg m/s. A 2000 kg truck at 10 m/s has the same momentum.

103 Impulse

Explanation: Impulse $J = F(\Delta t) = \Delta p = m(v_f - v_i)$. Units: N s (= kg m/s). A large force over a short time or small force over a long time can give the same impulse.

AP Physics Tip: Impulse = change in momentum. Area under F vs t graph = impulse. Crumple zones and airbags extend Δt to reduce force for the same impulse.

Example: A 1000 kg car stops from 20 m/s in 2 s: impulse = -20,000 N s; average force = 10,000 N. In 0.5 s: 40,000 N.

104 Impulse-Momentum Theorem

Explanation: $F(\text{avg}) \Delta t = \Delta p$. The net force times the contact time equals the change in momentum. This is Newton's second law in impulse form.

AP Physics Tip: $F(\text{avg}) = \Delta p / \Delta t$. Increasing contact time reduces average force (same momentum change) -- the physics of airbags, padding, bending knees.

Example: Catching a ball: pulling your hands back (longer Δt) reduces the force on your hands for the same momentum change.

105 Momentum Conservation

Explanation: In an isolated system (no external forces), total momentum is conserved: $p(i) = p(f)$. Internal forces (collisions) can't change total momentum.

AP Physics Tip: Conservation applies to the VECTOR sum of momenta. Choose a sign convention (direction) and keep it. Collisions, explosions, recoil all conserve momentum.

Example: Two carts collide and stick: $m_1v_1 + m_2v_2 = (m_1 + m_2)v(f)$. A rifle recoils because bullet + rifle momentum must stay zero.

106 Elastic Collisions

Explanation: Elastic: KE and momentum both conserved. In 1D with equal masses, velocities exchange. General 1D solution via conservation of both momentum and KE.

AP Physics Tip: Equal masses in elastic collision: they swap velocities. Otherwise use momentum + KE conservation (two equations, two unknowns).

Example: A 2 kg ball at 4 m/s hits a 2 kg ball at rest elastically: first stops, second moves at 4 m/s (velocities exchanged).

107 Inelastic & Perfectly Inelastic Collisions

Explanation: Inelastic: momentum conserved, KE lost (to heat/sound/deformation). Perfectly inelastic: objects stick (same final velocity); maximum KE loss. Momentum equation alone suffices.

AP Physics Tip: Perfectly inelastic: $m_1v_1 + m_2v_2 = (m_1 + m_2)v(f)$ -- one equation. KE loss = $KE(i) - KE(f)$.

Example: A 5 kg cart at 3 m/s hits a 3 kg cart at rest and they stick: $v(f) = 15/8 = 1.875$ m/s. KE lost: $22.5 \text{ J} - 8.8 \text{ J} = 13.7 \text{ J}$.

108 Explosions & Recoil

Explanation: Explosions are reverse collisions: total momentum before = 0, so pieces fly apart with equal and opposite momentum. Recoil of a rifle, skateboarder throwing a ball.

AP Physics Tip: $m_1v_1 + m_2v_2 = 0$ after an explosion from rest: $v_2 = -m_1v_1/m_2$. The lighter piece moves faster.

Example: A 60 kg astronaut throws a 2 kg wrench at 10 m/s: she recoils at $v = -(2 \times 10)/60 = -0.33$ m/s.

109 Center of Mass

Explanation: Center of mass (COM) is the mass-weighted average position. External forces move the COM as if all mass were concentrated there ($F = Ma(\text{com})$). Internal forces don't move it.

AP Physics Tip: *The COM of an isolated system moves at constant velocity -- collisions can't change it. This helps predict post-collision motion.*

Example: Two equal masses 4 m apart: COM is at the midpoint (2 m). In a collision, the COM continues at the same velocity.

110 Momentum in 2D

Explanation: In 2D collisions, momentum is conserved independently in x and y: $p(x,i) = p(x,f)$ and $p(y,i) = p(y,f)$. Solve component-wise, then combine.

AP Physics Tip: *Break velocities into components; conserve momentum in each axis separately. The final vector is the vector sum of components.*

Example: A ball hits a stationary ball at an angle: after collision, the two balls move in perpendicular directions if masses are equal and collision elastic.

111 Impulse Graphs

Explanation: Area under F-t graph = impulse = Δp . Peak force and duration trade off. A graph question asks: which collision has the largest impulse? Compare areas.

AP Physics Tip: *Impulse = area under F vs t. Higher peak or longer duration = more impulse = more momentum change.*

Example: Two force graphs, one tall and narrow, one short and wide: same area = same impulse.

112 Momentum & Collision Strategy

Explanation: 1) Identify the system and whether it's isolated. 2) Choose positive direction. 3) Write momentum conservation (components in 2D). 4) For elastic, also conserve KE. 5) Solve.

AP Physics Tip: *Momentum conservation is ALWAYS first. Add KE conservation only for elastic collisions. Track signs carefully.*

Example: For a 1D collision with unknown final velocities, set up $p(i) = p(f)$ and (for elastic) $KE(i) = KE(f)$, then solve the system.

113 Newton's Second Law & Momentum

Explanation: $F = \Delta p / \Delta t$ (force equals the rate of change of momentum). For constant mass, this reduces to $F = ma$. For rockets (changing mass), momentum form is essential.

AP Physics Tip: *$F = dp/dt$ generalizes $F = ma$. Rockets push exhaust backward; the rocket gains forward momentum (mass decreases over time).*

Example: A rocket ejects gas with momentum; the rocket gains equal opposite momentum -- $F = dp/dt$ handles the changing mass.

114 Conservation Laws: Which to Use

Explanation: Momentum: conserved in isolated systems (no external force) -- use for collisions/explosions. Energy: conserved when no external work/heat -- use for heights, speeds, springs. Both often together.

AP Physics Tip: *Collision -> momentum. Speed/height/spring -> energy. 'How fast after collision?' often needs both: momentum for the collision, energy for the motion after.*

Example: A bullet embeds in a block (momentum: $v \text{ after} = mv/(M+m)$), then the block swings up (energy: $1/2(M+m)v^2 = (M+m)gh$).

115 Ballistic Pendulum

Explanation: A projectile embeds in a block that swings up. Step 1: momentum conservation (inelastic collision). Step 2: energy conservation (swing). $v(\text{bullet}) = (M+m)/m \times \sqrt{2gh}$.

AP Physics Tip: *Two-step problem: momentum first (collision), energy second (swing). The height reached reveals the post-collision speed.*

Example: A 0.01 kg bullet embeds in a 1 kg block rising 0.2 m: $v(\text{after}) = \sqrt{2 \times 9.8 \times 0.2} = 1.98 \text{ m/s}$; $v(\text{bullet}) = 1.01 \times 1.98/0.01 = 200 \text{ m/s}$.

116 Force, Momentum, and Impulse in Sports

Explanation: Bouncing vs sticking: a ball bouncing reverses its momentum ($\Delta p = 2mv$), so it feels/transfers twice the impulse of one that stops ($\Delta p = mv$).

AP Physics Tip: *Bounce doubles the momentum change vs stick (for the same speed). That's why bouncing objects impart more impulse.*

Example: A 0.1 kg ball at 10 m/s hitting a wall and bouncing back at 10 m/s: $\Delta p = 2 \text{ kg m/s}$ (vs 1 kg m/s if it stuck).

117 Momentum of Systems & External Forces

Explanation: Total momentum of a system changes ONLY by external forces. Friction with the ground, gravity, and air are external to a colliding pair and can be neglected during the brief collision.

AP Physics Tip: *During a very brief collision, external forces (gravity, friction) have negligible impulse -- treat the system as isolated and conserve momentum.*

Example: Two cars colliding: their collision force is internal; road friction is small during the instant of impact, so momentum is ~conserved.

118 Comparing KE and Momentum

Explanation: $KE = p^2/(2m)$. Same momentum: lighter object has more KE. Same KE: heavier object has more momentum. This comparison appears in collision questions.

AP Physics Tip: *From $p = mv$ and $KE = 1/2mv^2$: $KE = p^2/2m$. Equal momentum $\rightarrow$ the lighter one has more KE. Equal KE $\rightarrow$ heavier has more momentum.*

Example: A 1 kg object and 4 kg object with the same momentum: the 1 kg object has 4x the KE.

119 Collisions with the Ground/Bounce

Explanation: When an object bounces off a surface, the floor impulse includes reversing the momentum. The normal force does positive work during the bounce (energy can be partially restored).

AP Physics Tip: *For a bounce, impulse = $m(v_f - v_i)$ with both speeds and signs. Coefficient of restitution = speed after / speed before (less than 1 loses energy).*

Example: A ball dropped from 1 m bounces to 0.5 m: it loses half its energy per bounce (energy scales with height).

120 Rocket Propulsion

Explanation: Rockets conserve momentum by expelling exhaust backward. Thrust = (mass flow rate) x (exhaust velocity). The rocket accelerates because its mass decreases while momentum changes.

AP Physics Tip: *Thrust = $(\Delta m / \Delta t) \times v(\text{exhaust})$. No air needed -- rockets work in space (they push exhaust, not air).*

Example: A rocket ejecting 50 kg/s of gas at 2,000 m/s has thrust = 100,000 N.

121 Impulse in Variable Forces

Explanation: For a force that varies with time (e.g., a collision), average force x time = impulse = area under the F-t curve. Peak forces exceed the average.

AP Physics Tip: *Use $F(\text{avg}) = \text{impulse} / \Delta t$. In car crashes, the average force during impact relates to stopping distance/time.*

Example: A 60 kg person decelerates from 15 m/s in 0.1 s: impulse = -900 N s, $F(\text{avg}) = 9,000$ N (about 15x body weight).

122 Momentum Conservation Problem Set

Explanation: Classic problems: stick-together collisions, elastic equal-mass swaps, explosions from rest, ballistic pendulums, 2D glancing collisions, recoiling cannons.

AP Physics Tip: *Master the pattern: isolated system $\rightarrow$ total p before = total p after. Write it vectorially; solve component-wise in 2D.*

Example: A 3 kg cannon fires a 0.5 kg ball at 40 m/s: cannon recoils at $v = -(0.5 \times 40)/3 = -6.67$ m/s.

123 Center-of-Mass Motion

Explanation: The center of mass of an isolated system moves at constant velocity -- internal forces (collisions, explosions) cannot change it. Pieces of an explosion arrange so the COM continues along its original path.

AP Physics Tip: *After an explosion, the COM keeps moving as if nothing happened. Use this to predict where the fragments land collectively.*

Example: A projectile explodes midair: the fragments scatter, but their COM continues the original parabolic path and lands where the unexploded shell would have.

124 Equal-Mass 2D Elastic Scattering

Explanation: In an elastic collision between two EQUAL masses where one is initially at rest, the final velocities are perpendicular: $\theta_1 + \theta_2 = 90$ degrees.

AP Physics Tip: *Equal masses, elastic, one at rest: the two final velocity vectors are perpendicular. Momentum + KE conservation force this.*

Example: A cue ball hits an identical ball at rest off-center: after the collision the two balls move at right angles to each other.

Explanation: For a ball bouncing off a wall, $\Delta p = m(v_f - v_i)$ with signs: if it rebounds at the same speed, $\Delta p = 2mv$ (double the 'stop' case). The wall's impulse is $2mv$.

AP Physics Tip: *Bouncing doubles the momentum change compared with stopping: impulse = $2mv$ vs mv . The floor/wall must supply this larger impulse.*

Example: A 0.2 kg ball at 8 m/s rebounds at 8 m/s: $\Delta p = 0.2(8 - (-8)) = 3.2 \text{ kg m/s}$. If it stuck, $\Delta p = 1.6 \text{ kg m/s}$.

Unit 6: Simple Harmonic Motion

12-18% of the exam. Oscillators: springs, pendulums, and the mathematics of periodic motion.

126 Simple Harmonic Motion (SHM) Definition

Explanation: SHM: motion where the restoring force is proportional to displacement and opposite in direction ($F = -kx$). The motion repeats with a constant period, tracing a sine wave.

AP Physics Tip: *SHM requires a linear restoring force: $F = -kx$. The motion is sinusoidal: $x(t) = A \cos(\omega t + \phi)$.*

Example: A mass on a spring and a pendulum at small angles are SHM oscillators.

127 Amplitude, Period, Frequency

Explanation: Amplitude A = maximum displacement from equilibrium. Period T = time for one full cycle (s). Frequency f = cycles per second (Hz). $T = 1/f$. In SHM, T and f are independent of amplitude.

AP Physics Tip: *$T = 1/f$ and $\omega = 2\pi/T = 2\pi f$. Remarkable fact: for a spring, T doesn't depend on amplitude -- bigger swings take the same time.*

Example: A mass-spring with $T = 0.5$ s has $f = 2$ Hz and $\omega = 12.6$ rad/s. Doubling the amplitude keeps $T = 0.5$ s.

128 Mass-Spring System

Explanation: For a mass on a spring: $T = 2\pi \sqrt{m/k}$, $\omega = \sqrt{k/m}$. Period increases with mass, decreases with stiffness. Independent of g and amplitude.

AP Physics Tip: *$T(\text{spring}) = 2\pi \sqrt{m/k}$: more mass = slower; stiffer spring = faster. Doubling mass multiplies T by $\sqrt{2}$.*

Example: $k = 100$ N/m, $m = 1$ kg: $T = 2\pi \sqrt{1/100} = 0.628$ s, $f = 1.59$ Hz.

129 Pendulum

Explanation: For a simple pendulum (small angles): $T = 2\pi \sqrt{L/g}$. Period depends on length and gravity ONLY -- not on mass or amplitude (small angles).

AP Physics Tip: *$T(\text{pendulum}) = 2\pi \sqrt{L/g}$: longer string = slower; higher g = faster. Mass cancels -- a heavy bob and light bob swing identically.*

Example: A 1 m pendulum: $T = 2\pi \sqrt{1/9.8} = 2.01$ s. On the Moon ($g/6$): $T = 4.92$ s (slower).

130 Restoring Force & Equilibrium

Explanation: In SHM, the force always points back toward equilibrium (opposite displacement). At equilibrium, force and acceleration are zero, but velocity is maximum. At extremes, force/acceleration maximum, velocity zero.

AP Physics Tip: *Equilibrium: $F = 0$, $a = 0$, $v = \text{max}$. Extremes: $F = \text{max}$, $a = \text{max}$, $v = 0$. The energy sloshes between KE and U.*

Example: A mass on a spring passes equilibrium at max speed; at full compression/stretch it momentarily stops with max spring force.

131 Energy in SHM

Explanation: Total energy $E = 1/2kA^2$ (constant). At any x : $E = 1/2kx^2 + 1/2mv^2$. At equilibrium: $E = 1/2mv(\text{max})^2$. At extremes: $E = 1/2kA^2$.

AP Physics Tip: *$E(\text{total}) = 1/2kA^2$ at all times. $v(\text{max}) = A \sqrt{k/m}$. KE + U(s) is constant, converting back and forth.*

Example: Mass 0.5 kg, $k = 200$ N/m, $A = 0.1$ m: $E = 1/2(200)(0.01) = 1$ J; $v(\text{max}) = 0.1 \sqrt{400} = 2$ m/s.

132 Position, Velocity, Acceleration in SHM

Explanation: $x(t) = A \cos(\omega t)$; $v(t) = -A \omega \sin(\omega t)$; $a(t) = -A \omega^2 \cos(\omega t) = -\omega^2 x$. Acceleration is proportional and opposite to displacement.

AP Physics Tip: *$a = -\omega^2 x$ is the SHM signature. Velocity leads position by 90 degrees; acceleration is 180 degrees out of phase with position.*

Example: At $x = +A/2$, acceleration = $-\omega^2(A/2)$ (toward equilibrium); velocity is nonzero and moving toward equilibrium.

133 Phase & Phase Constant

Explanation: Phase ($\omega t + \phi$) tracks where in the cycle the oscillator is. The phase constant ϕ sets the starting position (e.g., starting at max displacement vs at equilibrium).

AP Physics Tip: Starting at maximum displacement: $x = A \cos(\omega t)$. Starting at equilibrium moving positive: $x = A \sin(\omega t)$.

Example: A pendulum released from rest at max angle starts at $x = A$ ($\phi = 0$). One pushed from equilibrium starts with $\phi = \pi/2$.

134 Damping

Explanation: Damped oscillation: friction/drag removes energy, so amplitude decays exponentially. Overdamped (no oscillation, slow return), underdamped (oscillates, decaying), critically damped (fastest return without oscillation).

AP Physics Tip: Damping reduces amplitude over time but barely changes the period (light damping). Critical damping returns fastest without overshoot -- used in door closers, car shocks.

Example: A car's shock absorbers are tuned near critical damping: the car returns to level quickly without bouncing.

135 Forced Oscillations & Resonance

Explanation: When a periodic driving force matches the natural frequency, amplitude grows dramatically -- resonance. Examples: pushing a swing, Tacoma Narrows Bridge, opera singer breaking glass.

AP Physics Tip: Resonance occurs when driving frequency = natural frequency ($\omega = \sqrt{k/m}$ or $\sqrt{g/L}$). Amplitude spikes and can be destructive.

Example: Pushing a swing at its natural frequency builds amplitude with each push. Troops break step crossing bridges to avoid resonant vibration.

136 SHM vs Circular Motion

Explanation: Uniform circular motion projected onto one axis IS SHM: $x = A \cos(\omega t)$. ω (angular velocity) of the circle equals ω (angular frequency) of the SHM.

AP Physics Tip: The projection of circular motion onto a diameter gives perfect SHM -- this is the geometric origin of the sine wave.

Example: A point on a rotating wheel's edge casts a shadow that oscillates in SHM along the wall.

137 Graphs of SHM

Explanation: x - t : cosine curve. v - t : sine curve (90 degrees ahead). a - t : negative cosine (180 degrees from x). Periods are the same; amplitudes relate by factors of ω .

AP Physics Tip: Compare graphs by phase: v peaks when $x = 0$; a peaks when x is at extremes. These phase relationships are common AP questions.

Example: When x is at $+A$, $v = 0$ and $a = -\omega^2 A$ (maximum, opposite). When $x = 0$, $v = \pm v(\max)$, $a = 0$.

138 Maximum Values in SHM

Explanation: $v(\max) = A \omega = A \sqrt{k/m}$; $a(\max) = A \omega^2 = kA/m$; $F(\max) = kA$. All scale with amplitude.

AP Physics Tip: $v(\max) = A \omega$; $a(\max) = A \omega^2$. Memorize these three max values -- they appear in nearly every SHM problem.

Example: $A = 0.2$ m, $\omega = 5$ rad/s: $v(\max) = 1$ m/s, $a(\max) = 5$ m/s².

139 Vertical Mass-Spring

Explanation: A mass hanging on a spring oscillates about the equilibrium where $mg = kx(\text{eq})$. The SHM is identical to horizontal (same $\omega = \sqrt{k/m}$); gravity just shifts equilibrium.

AP Physics Tip: Gravity shifts the equilibrium position ($x(\text{eq}) = mg/k$) but does NOT change the period or frequency. Same $\omega = \sqrt{k/m}$.

Example: A 2 kg mass stretches a spring 0.2 m at equilibrium: $k = mg/x = 98$ N/m. Pull it further and it oscillates with $\omega = \sqrt{98/2} = 7$ rad/s.

140 Simple Pendulum at Large Angles

Explanation: For large angles, the small-angle approximation ($\sin \theta \sim \theta$) fails; the period increases slightly with amplitude. AP Physics 1 uses small angles (T independent of amplitude).

AP Physics Tip: The formula $T = 2\pi \sqrt{L/g}$ is valid for small angles ($< \sim 15$ degrees). At large amplitudes the period lengthens.

Example: A pendulum released from 60 degrees swings a bit slower than the small-angle formula predicts.

141 Spring Combinations in SHM

Explanation: Springs in parallel: $k(\text{eff}) = k_1 + k_2$, faster oscillation. In series: $1/k(\text{eff}) = 1/k_1 + 1/k_2$, slower. The period follows from $k(\text{eff})$.

AP Physics Tip: *Parallel = stiffer = shorter period. Series = softer = longer period. Use $k(\text{eff})$ in $T = 2\pi \sqrt{m/k}$.*

Example: Two identical springs (k each) parallel: $k(\text{eff}) = 2k$, T multiplied by $\sqrt{1/2}$. In series: $k(\text{eff}) = k/2$, T multiplied by $\sqrt{2}$.

142 Oscillator & Energy Conservation

Explanation: SHM obeys energy conservation exactly (no friction): $\frac{1}{2}mv^2 + \frac{1}{2}kx^2 = \frac{1}{2}kA^2$. Solve for v at any x : $v = \omega \sqrt{A^2 - x^2}$.

AP Physics Tip: *$v = \omega \sqrt{A^2 - x^2}$ gives speed at any position. At $x = 0$: $v = \omega A$ (max). At $x = A$: $v = 0$.*

Example: $A = 0.1$ m, $\omega = 10$: at $x = 0.06$ m, $v = 10 \sqrt{(0.01 - 0.0036)} = 0.8$ m/s.

143 Pendulum Clock & g Measurement

Explanation: Pendulum period measures local gravity: $g = 4\pi^2 L / T^2$. Pendulum clocks run slower where g is smaller (or L longer).

AP Physics Tip: *Use $T = 2\pi \sqrt{L/g}$ to measure g from L and T . Longer pendulum = slower clock; a clock moved to lower g runs slow.*

Example: A clock with $L = 0.248$ m has $T = 1.0$ s on Earth ($g = 9.8$). On a planet with $g = 3.92$, the same pendulum has $T = 1.58$ s.

144 Energy Plots in SHM

Explanation: $U(x) = \frac{1}{2}kx^2$ is a parabola; $KE = E - U$ is the gap. Total energy is a horizontal line at $\frac{1}{2}kA^2$. Turning points at $x = \pm A$ where $KE = 0$.

AP Physics Tip: *Read KE off the energy diagram as the gap between the total-energy line and the U parabola. At $x = 0$, the gap is largest (max KE).*

Example: For $E = 1$ J with $U = \frac{1}{2}kx^2$, $KE = 0$ only at the turning points $x = \pm A$; everywhere inside, $KE > 0$.

145 SHM in Different Contexts

Explanation: SHM appears in: mass-springs, pendulums, molecules vibrating, tuning forks, guitar strings (standing waves), and LC circuits (AP Physics 2). All share the same math.

AP Physics Tip: *Recognize SHM by the signature: restoring force proportional to displacement. The same equations apply to any oscillator.*

Example: A tuning fork's tines vibrate in SHM, producing a pure sine tone. A guitar string's vibration is a superposition of SHM modes.

146 SHM & Circular Motion Lab Connections

Explanation: Labs: measure T for a mass-spring vs m (graph T^2 vs m gives slope $4\pi^2/k$); measure T of a pendulum vs L (T^2 vs L slope $4\pi^2/g$).

AP Physics Tip: *T^2 vs m for a spring is linear (slope $4\pi^2/k$). T^2 vs L for a pendulum is linear (slope $4\pi^2/g$). These lab graphs are AP favorites.*

Example: From a T^2 vs L graph slope of $4.0 \text{ s}^2/\text{m}$: $g = 4\pi^2/4.0 = 9.87 \text{ m/s}^2$.

147 Phase Relationships Summary

Explanation: Position leads velocity by 90 degrees ($v = -A\omega \sin$); acceleration is opposite position (180 degrees). x and a are in antiphase; x and v are quadrature.

AP Physics Tip: *If $x = A \cos(\omega t)$, then v peaks a quarter-period later and a peaks a half-period later. Use this to match graphs.*

Example: At $t = 0$ with $x = A$: $v = 0$, $a = -\omega^2 A$. A quarter period later: $x = 0$, $v = -\omega A$ (moving through equilibrium).

148 Natural Frequency & Resonance

Explanation: The natural frequency $\omega = \sqrt{k/m}$ (spring) or $\sqrt{g/L}$ (pendulum) is the frequency a system oscillates at when undisturbed. A driving force at this frequency causes resonance (growing amplitude).

AP Physics Tip: *Resonance: driving frequency = natural frequency $\rightarrow$ maximum amplitude. Natural frequency depends only on the system's properties (k , m , L , g).*

Example: A swing's natural frequency is set by its length; pushing at exactly that rhythm makes it swing higher and higher.

149

Physical Pendulum (Conceptual)

Explanation: A physical pendulum is any rigid body pivoted off its center of mass. Its period depends on the moment of inertia about the pivot: $T = 2\pi \sqrt{I/(Mgd)}$ where d = pivot-to-COM distance. AP Physics 1 treats this conceptually.

AP Physics Tip: *Physical pendulum: heavier distribution farther from the pivot (larger I) swings slower. A meter stick hung at one end oscillates like a physical pendulum.*

Example: A uniform rod pivoted at its end has a longer period than a simple pendulum of the same length -- its mass is distributed, not concentrated at the bob.

150

SHM from Initial Conditions

Explanation: Given initial position and velocity, choose sine or cosine: $x = A \cos(\omega t)$ starts at maximum displacement; $x = A \sin(\omega t)$ starts at equilibrium moving positive. The phase constant fits the start.

AP Physics Tip: *Start at max displacement -> cosine. Start at equilibrium moving positive -> sine. The amplitude and phase are set by where the motion begins.*

Example: A mass released from $x = +A$ starts with $x = A \cos(\omega t)$. One pushed from equilibrium with $+v$ starts as $x = A \sin(\omega t)$ (phase $\pi/2$ ahead of cosine).

Unit 7: Torque & Rotational Motion

12-18% of the exam. Torque, rotational kinematics/dynamics, angular momentum, and rotational energy.

151 Torque

Explanation: Torque $\tau = r F \sin(\theta) = r(\text{perpendicular}) F = r F(\text{perpendicular})$. Units: N m. Torque twists; it depends on force, distance from pivot, and angle.

AP Physics Tip: $\tau = r \times F \sin(\theta)$. Maximize torque by pushing perpendicular ($\theta = 90^\circ$) far from the pivot. A force through the pivot produces zero torque.

Example: Opening a door: push at the handle (large r), perpendicular ($\theta = 90^\circ$). Pushing near the hinge (small r) or parallel to the door does little.

152 Lever Arm

Explanation: The lever arm is the perpendicular distance from the pivot to the line of action of the force. Torque = force x lever arm. Long lever arms multiply force.

AP Physics Tip: $\text{Lever arm} = r \sin(\theta)$ -- the perpendicular distance. Identify it first in every torque problem.

Example: A 100 N force at 2 m from the pivot, applied at 30 degrees: lever arm = $2 \sin 30 = 1$ m, $\tau = 100$ N m.

153 Torque Sign Convention

Explanation: Torque has direction: counterclockwise = positive, clockwise = negative (by convention). Use signs in equilibrium and dynamics equations.

AP Physics Tip: Pick a convention (CCW positive) and apply it consistently. The net torque is the signed sum.

Example: A 5 N m CCW torque and a 3 N m CW torque give net +2 N m (CCW).

154 Rotational Equilibrium

Explanation: Conditions for equilibrium: net force = 0 AND net torque = 0. Static equilibrium: at rest. Sum torques about any pivot point to solve.

AP Physics Tip: Equilibrium needs BOTH $\sum F = 0$ and $\sum \tau = 0$. Choose the pivot at the unknown force to eliminate it from the torque equation.

Example: A seesaw balances when $m_1 g r_1 = m_2 g r_2$ about the fulcrum. A ladder against a wall needs torque balance about the base.

155 Center of Mass & Balance

Explanation: An object balances when supported at its center of mass. The torque due to weight acts at the COM. For extended objects, weight acts through the COM.

AP Physics Tip: Weight acts at the COM (torque = $Mg \times \text{distance from pivot to COM}$). Stability: an object tips when the COM passes beyond its support base.

Example: A meter stick balances at 50 cm. A 2 kg mass at the 10 cm mark needs a counterweight: $2 \times 0.4 = M \times 0.5 \rightarrow M = 1.6$ kg at the 90 cm end... check distances.

156 Rotational Kinematics

Explanation: Angular analogs: θ (rad), ω (rad/s), α (rad/s²). Equations mirror linear: $\omega = \omega_0 + \alpha t$; $\theta = \omega_0 t + \frac{1}{2} \alpha t^2$; $\omega^2 = \omega_0^2 + 2 \alpha \theta$.

AP Physics Tip: Rotational kinematics equations are the same as linear with $\theta/\omega/\alpha$. Convert to linear at the rim: $v = \omega r$, $a(\text{tangential}) = \alpha r$.

Example: A wheel spins up from rest at $\alpha = 2$ rad/s² for 5 s: $\omega = 10$ rad/s; $\theta = \frac{1}{2}(2)(25) = 25$ rad.

157 Moment of Inertia

Explanation: Moment of inertia $I = \sum(m r^2)$: rotational mass, resistance to angular acceleration. Depends on mass AND how it's distributed from the axis. Units: kg m².

AP Physics Tip: I depends on the axis: a rod about its center ($I = \frac{1}{12} mL^2$) vs its end ($I = \frac{1}{3} mL^2$). Mass farther from the axis = larger I .

Example: A hoop ($I = mR^2$) is harder to spin than a disk ($I = \frac{1}{2}mR^2$) of the same mass and radius -- the hoop's mass is all at the rim.

158 Rotational Inertia Formulas

Explanation: Hoop: $I = mR^2$. Disk/cylinder: $I = \frac{1}{2}mR^2$. Solid sphere: $I = \frac{2}{5}mR^2$. Thin rod center: $I = \frac{1}{12}mL^2$; rod end: $\frac{1}{3}mL^2$.

AP Physics Tip: Know the common formulas: hoop = mR^2 (all mass at rim), disk = $\frac{1}{2}mR^2$, solid sphere = $\frac{2}{5}mR^2$, rod center = $\frac{1}{12}mL^2$.

Example: Two disks of the same mass and radius: the solid disk ($\frac{1}{2}mR^2$) rolls faster than a hoop (mR^2) down a ramp -- less rotational inertia.

159 Newton's Second Law for Rotation

Explanation: $\tau(\text{net}) = I \alpha$. The net torque equals moment of inertia times angular acceleration -- the rotational $F = ma$. Larger I means smaller α for the same torque.

AP Physics Tip: $\tau = I \alpha$ is the rotational second law. Apply it with a sign convention and consistent axis.

Example: A torque of 10 N m on a disk with $I = 2 \text{ kg m}^2$: $\alpha = 5 \text{ rad/s}^2$. If I doubles, α halves.

160 Rotational Kinetic Energy

Explanation: $KE(\text{rot}) = \frac{1}{2} I \omega^2$. Rolling objects have both translational KE ($\frac{1}{2}mv^2$) and rotational KE ($\frac{1}{2}I \omega^2$). Total KE of a rolling object = sum.

AP Physics Tip: For rolling without slipping: $v = \omega R$. Total KE = $\frac{1}{2}mv^2 + \frac{1}{2}I \omega^2$. Use energy conservation including BOTH terms.

Example: A solid sphere rolling: $KE(\text{total}) = \frac{1}{2}mv^2 + \frac{1}{2}(\frac{2}{5}mR^2)(v/R)^2 = \frac{7}{10}mv^2$.

161 Rolling Without Slipping

Explanation: Rolling without slipping: $v(\text{com}) = \omega R$ (point of contact is instantaneously at rest). Static friction does no work on a rolling object (contact point doesn't slide).

AP Physics Tip: $v = \omega R$ is the rolling condition. Friction supplies torque but does no work when rolling without slipping.

Example: A wheel of radius 0.3 m rolling at 10 m/s spins at $\omega = 10/0.3 = 33.3 \text{ rad/s}$.

162 Rolling Down an Incline

Explanation: Objects rolling down an incline conserve energy: $mgh = \frac{1}{2}mv^2 + \frac{1}{2}I \omega^2$. The object with the SMALLEST I (per mass) reaches the bottom first.

AP Physics Tip: Race order (frictionless rolling): solid sphere > disk > hoop (smallest I/mR^2 wins). All have the same mgh available; more energy into rotation = slower translation.

Example: Down a ramp: solid sphere ($I = \frac{2}{5}mR^2$) beats disk ($\frac{1}{2}$) beats hoop (1). The hoop converts the most energy to rotation, so it lags.

163 Angular Momentum

Explanation: Angular momentum $L = I \omega$ ($\text{kg m}^2/\text{s}$). Conservation: if net external torque is zero, L is constant. I can change (pull arms in) and ω compensates.

AP Physics Tip: $L = I \omega$ conserved when net $\tau = 0$. Decreasing I increases ω -- the spinning skater effect. Direction: along the axis (right-hand rule).

Example: A figure skater pulls arms in: I drops, ω jumps, L stays the same. An ice skater spinning slowly with arms out spins faster with arms in.

164 Conservation of Angular Momentum

Explanation: If no external torque: $I_1 \omega_1 = I_2 \omega_2$. Internal forces (pulling in mass) can't change L . Used in: skaters, divers (tuck to spin faster), neutron stars collapsing.

AP Physics Tip: $I_1 \omega_1 = I_2 \omega_2$. Tuck = smaller I = faster spin. A collapsing star spins up dramatically (conservation of L).

Example: A skater with $I = 2 \text{ kg m}^2$ at $\omega = 3 \text{ rad/s}$ pulls in to $I = 1 \text{ kg m}^2$: $\omega = 6 \text{ rad/s}$.

165 Angular Impulse

Explanation: Angular impulse = $\tau \Delta t = \Delta L$ (change in angular momentum). A torque applied over time changes L , just as force over time changes p .

AP Physics Tip: $\tau \Delta t = \Delta L = I \Delta \omega$. This is the rotational impulse-momentum theorem.

Example: A torque of 4 N m applied for 2 s gives angular impulse 8 N m s, changing L by $8 \text{ kg m}^2/\text{s}$.

166 Torque & Angular Acceleration Problems

Explanation: Combine $\tau = I\alpha$ with kinematics: find α from torque, then use rotational kinematics for ω / θ . Include friction torques with signs.

AP Physics Tip: $\tau_{\text{net}} = I\alpha$ first, then rotational kinematics. Friction torque opposes motion (negative).

Example: A 4 N m net torque on $I = 2 \text{ kg m}^2$ from rest for 3 s: $\alpha = 2 \text{ rad/s}^2$; $\omega = 6 \text{ rad/s}$; $\theta = 9 \text{ rad}$.

167 Static Equilibrium Problems (Ladders, Planks)

Explanation: Ladder/plank problems: three conditions -- $\sum F_x = 0$, $\sum F_y = 0$, $\sum \tau = 0$ (about any pivot). Friction at the base, normal forces at wall/ground.

AP Physics Tip: Pick the pivot at the point with the most unknowns (usually the base) to cancel those torques. Then solve F_x , F_y , τ equations.

Example: A ladder leans against a frictionless wall: normal at wall (horizontal), friction + normal at ground. Torque about the base gives the wall force.

168 Torque Due to Weight

Explanation: For an extended object, the weight acts at the center of mass. Torque from weight = $Mg \times$ (horizontal distance from pivot to COM).

AP Physics Tip: The weight's torque uses the horizontal distance from the pivot to the COM. This is how seesaws and planks balance.

Example: A 10 m plank (weight 200 N, COM at 5 m) pivots at one end: weight torque = $200 \times 5 = 1,000 \text{ N m}$ (trying to rotate it down).

169 Rotational Work & Power

Explanation: Work (rotational) = $\tau \Delta \theta$. Power = $\tau \omega$. Rotational work-energy: $\tau \Delta \theta = \Delta(\frac{1}{2} I \omega^2)$.

AP Physics Tip: $W = \tau \theta$; $P = \tau \omega$. Rotational work-energy mirrors the linear version.

Example: A motor applies 20 N m torque for 3 radians: work = 60 J. At $\omega = 10 \text{ rad/s}$, power = 200 W.

170 Comparing Linear & Rotational

Explanation: $m \rightarrow I$, $F \rightarrow \tau$, $p \rightarrow L$, $KE \rightarrow \frac{1}{2} I \omega^2$, $F = ma \rightarrow \tau = I\alpha$, p conservation $\rightarrow L$ conservation. Every linear concept has a rotational twin.

AP Physics Tip: Use the analogy table to translate: force $\rightarrow$ torque, mass $\rightarrow$ inertia, momentum $\rightarrow$ angular momentum, etc. This unlocks rotational problems.

Example: Linear: $F = ma$, $p = mv$, $KE = \frac{1}{2}mv^2$. Rotational: $\tau = I\alpha$, $L = I\omega$, $KE = \frac{1}{2}I\omega^2$.

171 Gyroscopes & Spinning Stability

Explanation: A spinning object resists changes to its axis (angular momentum is a vector). This gyroscopic stability keeps bicycle wheels up and tops spinning.

AP Physics Tip: L is a vector along the spin axis; external torques change its direction (precession), not just magnitude. Spinning stabilizes orientation.

Example: A bicycle is stable at speed because the spinning wheels' angular momentum resists tipping. A top precesses rather than falling.

172 Rotational Dynamics in Systems

Explanation: Systems with pulleys: combine linear $F = ma$ for hanging masses with rotational $\tau = I\alpha$ for the pulley ($a = \alpha R$ at the rim).

AP Physics Tip: Pulley with mass: T_1 and T_2 differ (the pulley needs torque to spin). Relate: $(T_1 - T_2)R = I\alpha$ and $a = \alpha R$.

Example: A 2 kg mass unwinds a string from a disk pulley ($I = \frac{1}{2}mR^2$): solve $mg - T = ma$ and $TR = I\alpha$ with $a = \alpha R$.

173 Rotational Energy with Rolling

Explanation: A rolling object's energy splits: $KE_{\text{total}} = \frac{1}{2}mv^2(1 + I/mR^2)$. The factor $(1 + I/mR^2)$ is 1.5 for a hoop, 1.4 for a disk... memorize the idea, not the decimals.

AP Physics Tip: Energy conservation with rolling: $mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$, then substitute $v = \omega R$ to solve for v . Smaller $I \rightarrow$ larger final v .

Example: A disk ($I = \frac{1}{2}mR^2$) from rest height h : $mgh = \frac{1}{2}mv^2 + \frac{1}{2}(\frac{1}{2}mR^2)(v/R)^2 = \frac{3}{4}mv^2 \rightarrow v = \sqrt{4gh/3}$.

174 Rotational Dynamics Strategy

Explanation: 1) Identify the pivot. 2) Compute each torque ($r F \sin \theta$, sign convention). 3) Write $\tau(\text{net}) = I \alpha$ (or $= 0$ at equilibrium). 4) Add kinematics/energy as needed. 5) Check units (N m, kg m², rad/s²).

AP Physics Tip: *Torque problems: choose pivot wisely, use lever arms, keep signs straight. Rotational energy is the shortcut for speed problems.*

Example: For 'speed at the bottom' questions, energy conservation (with rotation) is faster than dynamics. For forces/tensions, use $\tau = I \alpha$.

175 Right-Hand Rule for Rotation

Explanation: Right-hand rule: curl fingers in the direction of rotation (or torque); the thumb points along the axis (positive angular velocity/torque direction). Angular momentum points along the spin axis.

AP Physics Tip: *Use the right-hand rule to assign signs: rotation CCW viewed from the thumb side is positive. L and ω point along the axis of rotation.*

Example: A wheel spinning CCW (viewed from the right) has angular velocity pointing right along its axle. Torque directions follow the same rule.

176 See-Saw Torque Balance

Explanation: A balanced see-saw satisfies $m_1 g r_1 = m_2 g r_2$ about the fulcrum. Heavier mass sits closer; lighter sits farther. Adding mass on one side requires moving the other out or adding counterweight.

AP Physics Tip: *Equilibrium: sum of torques = 0. For a see-saw, weight torque = $mg \times \text{distance from fulcrum}$. Solve $m_1 r_1 = m_2 r_2$.*

Example: A 40 kg child 1.5 m from the fulcrum balances a 60 kg child at $r = (40 \times 1.5)/60 = 1.0$ m on the other side.

What's Next?

You have now reviewed every unit of the AP Physics 1 course. The concepts that matter most are the ones you almost knew -- go back to the Table of Contents, find the units you marked, and reread just those tip lines. Two weeks out, do a rapid pass over the entire guide; the day before, review only the tip lines. On exam day, write your equations symbolically before plugging numbers, show units on every answer, and check that your final answer is physically reasonable.

Pair it with the Study Mastery Cheat Sheet (\$19) -- how to actually retain all of it

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