AP Physics C: Mechanics

AP Physics C lab questions expect the AP Physics 1 method plus calculus: a slope that is a derivative, an area that is an integral, and a linearization that may need a little algebra first. *C*
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The Experimental Design and Analysis question

One of the four free-response questions is a lab question. It asks you to design a procedure, say how you would graph the data so the graph is a straight line, and then work with data – plot it, find a slope, and say what the slope tells you. It is not about naming fancy apparatus; it is about what you measure and what you do with the numbers.

Read the question for what is GIVEN and what is to be DETERMINED. The quantity to be determined is almost always the slope (or the intercept) of the graph you are about to design.

Answer every part, even if an earlier part went wrong. The graph and slope parts are marked on what you plotted, not on whether your design matched the reference.

Writing the procedure

Name each quantity you will measure AND the instrument that measures it: 'a meterstick to measure the height h of the ramp' earns the point; 'a meterstick' does not.

Vary the independent variable over a RANGE – at least five values, spread out. One measurement cannot give a slope.

Say what you hold constant and how. 'Use the same cart, released from rest from the same mark each time'.

Repeat each trial and average. Say that this reduces RANDOM error; it does nothing for a systematic one.

Remove a specific systematic error by name: zero the force sensor, measure to the center of mass, start timing from a fixed release, use a motion detector instead of a hand-held stopwatch.

Write the steps so someone else could follow them: numbered, in order, with each measurement said once. A paragraph of good intentions loses points that a numbered list keeps.

Linearizing the data

Almost every design question wants a straight-line graph. Start from the equation, put the quantity you control on one side and the one you measure on the other, and match it to y = mx + b.

Relationship	**Plot y**	**against x**	**Slope**
$a = g\sin\theta$	a	$\sin\theta$	g
$T = 2\pi\sqrt{L/g}$	T^2	L	$4\pi^2/g$
$T = 2\pi\sqrt{m/k}$	T^2	m	$4\pi^2/k$
$v^2 = 2gh$	v^2	h	$2g$
$F = kq_1q_2/r^2$	F	$1/r^2$	kq_1q_2
$1/s_o + 1/s_i = 1/f$	$1/s_i$	$1/s_o$	-1 (intercept $1/f$)
$V = V_0e^{-t/RC}$	$\ln V$	t	$-1/RC$

Write down what the slope equals, in symbols, BEFORE you take data. That sentence is usually a point on its own.

Units of the slope are the y-unit over the x-unit. For T^2 against L that is s^2/m – and checking it against $4\pi^2/g$ (units s^2/m) is a quick way to catch a wrong plot.

A constant you multiply by does not stop a line being straight; a power or a square root does. If the equation has one, plot that power.

The graph and its slope

Label both axes with the quantity and its unit, and pick scales that spread the data over most of the grid.

Plot the points; do not connect the dots. Draw ONE straight best-fit line with points scattered on both sides.

Find the slope from two points ON THE LINE, far apart, and show the calculation. Two data points are not the line unless the line happens to pass through them.

Say what the slope means and calculate the quantity from it, with units: 'slope = $4\pi^2/g$, so $g = 4\pi^2/\text{slope} = 9.7\ m/s^2$'.

If the theory says the line passes through the origin and yours does not, the intercept points to a systematic error. Name a plausible one: friction, a reaction time, a zero offset, the mass of a hanger left out.

Error and agreement

Percent difference – $|\text{experimental} - \text{accepted}| \div \text{accepted} \times 100\%$. A few percent is good agreement for a school lab

Random error – scatter about the line; reduced by repeating trials and by a best-fit line through many points

Systematic error – shifts every point the same way; it shows up as a wrong slope or an unexpected intercept, and repeating does not remove it

When asked how an error affects the result, push it through the equation and the graph: 'measuring L to the top of the bob makes every L too short by the bob's radius; that shifts the line sideways, so it shows in the intercept and leaves the slope – and g – unchanged'. Guessing a direction without the reasoning earns nothing.

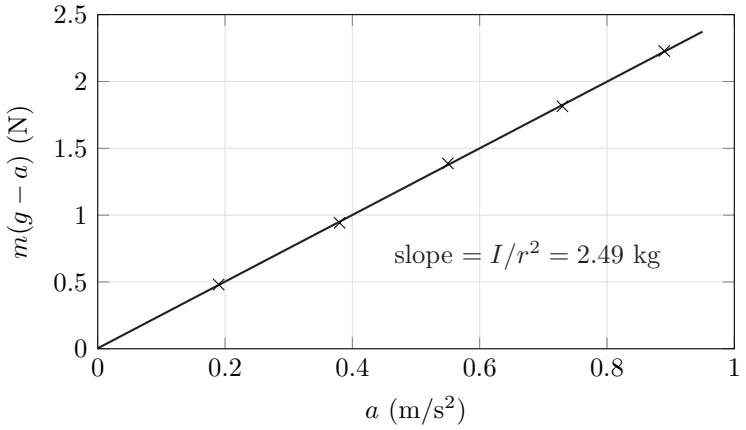
'Human error' and 'measure more carefully' are not sources of error. Name the measurement and what goes wrong with it.

Worked analysis: the rotational inertia of a pulley

A string wound round an axle of radius r = 0.020 m carries a hanging mass m. Released from rest, the mass falls with acceleration a, measured with a motion detector. For the mass, mg − T = ma; for the pulley, Tr = Iα = I a/r. Eliminating T: m(g − a) = (I/r^2) a.

So plot m(g − a) on the y-axis against a on the x-axis: a line through the origin with slope I/r^2. Neither variable is the 'independent' one you set – m is – but this is the pair that makes the line straight.

m (kg)	0.050	0.100	0.150	0.200	0.250
a (m/s^2), mean of 3	0.19	0.38	0.55	0.73	0.89
$m(g-a)$ (N)	0.481	0.942	1.387	1.814	2.228



Using g = 9.8 m/s^2. The line passes through the origin, as the model predicts.

I = slope × r^2 = 2.49 kg × (0.020 m)^2 = 1.0 × 10^{-3} kg · m^2. The units check: N ÷ (m/s^2) = kg, and kg × m^2 is a rotational inertia.

Friction in the axle adds a roughly constant torque τ_f that the model leaves out: m(g − a) = (I/r^2) a + τ_f/r. It lifts the whole line by τ_f/r without changing its slope, so the slope still gives I – but a line forced through the origin would not. A positive y-intercept is the tell-tale; here it is 0.003 N, so friction is negligible.

Slopes and areas – the calculus in a lab question

The slope of a position–time graph is the velocity; of a velocity–time graph, the acceleration. Read it from a tangent at the instant asked for, drawn with a ruler, and show the two points you used.

The area under a force–time graph is the impulse, and so the change in momentum. Count squares or split the area into triangles and rectangles, and give the units N · s.

The area under a force–position graph is the work done. For a spring that is ½kx^2, the triangle under F = kx.

An experiment with a non-constant force is still linearizable: for linear drag F = −bv, the terminal speed is $v_T = mg/b$, so v_T against m is a line of slope g/b.

Labs that keep coming back

Impulse and momentum – a cart hits a force sensor; the area under F–t from the sensor equals the change in mv measured by a motion detector. The comparison of the two IS the experiment

Drag and terminal speed – stacks of coffee filters dropped in front of a motion detector; the speed levels off. Terminal speed against mass tests linear drag; terminal speed squared against mass tests drag $\propto v^2$

Spring–mass oscillator – T^2 against m has slope $4\pi^2/k$. A non-zero intercept on the m-axis reflects the spring's own mass, roughly a third of which also oscillates

Physical pendulum – a meterstick swinging about holes at distance d from its center; the period depends on I about the pivot, given by the parallel-axis theorem. Plot T^2 d against d^2 for a straight line

Conservation of angular momentum – drop a ring onto a spinning disk on a rotary sensor; $I\omega$ before equals $I\omega$ after if the axle's friction torque acts only briefly. Kinetic energy is NOT conserved in this collision

Work and energy with a spring – pull a cart with a force sensor while a motion detector records position; the area under F–x matches the change in kinetic energy