
AP Physics C: E&M lab questions are circuits, fields and induction, and the analysis is often exponential: a capacitor or an inductor changing over time, made straight with a natural log.

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 $1/f$)
$V = V_0 e^{-t/RC}$	$\ln V$	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 $g = 4\pi^2/\text{slope} = 9.7 \text{ m/s}^2$ ’.

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.

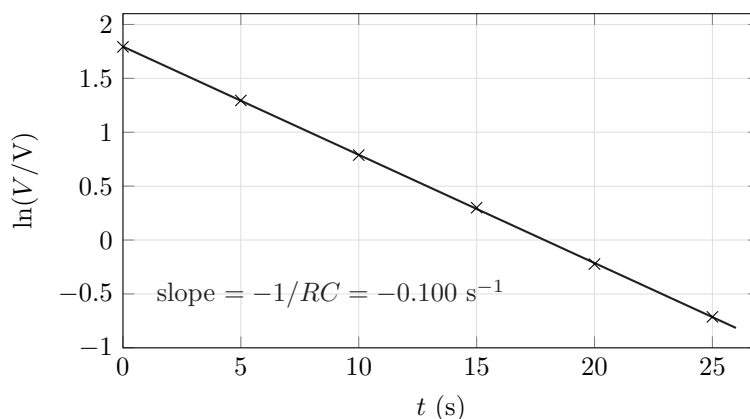
‘Human error’ and ‘measure more carefully’ are not sources of error. Name the measurement and what goes wrong with it.

Worked analysis: the time constant of an RC circuit :RC

A capacitor charged to 6.00 V discharges through a 100 k Ω resistor while a voltage sensor records V across it. Model: $V = V_0 e^{-t/RC}$, so $\ln V = \ln V_0 - t/RC$. A graph of $\ln V$ against t is a line of slope $-1/RC$.

t (s)	0	5.0	10.0	15.0	20.0	25.0
V (V)	6.00	3.65	2.20	1.35	0.80	0.49
$\ln(V/V_0)$	1.792	1.295	0.788	0.300	-0.223	-0.713

The log of a voltage is taken of the number, $V \div (1 \text{ V})$, so $\ln V$ has no unit.



A straight line confirms the exponential model; a curve would mean it does not hold, or that the meter draws current.

Slope = -0.100 s^{-1} , so $RC = 10.0 \text{ s}$, and $C = 10.0 \text{ s} \div 100\,000 \, \Omega = 1.00 \times 10^{-4} \text{ F} = 100 \, \mu\text{F}$.

The voltmeter has its own resistance in parallel with R. If it is not much larger than 100 k Ω the capacitor discharges through both, faster than through R alone, and C comes out too SMALL. A sensor with a very high input resistance avoids this.

Time to half voltage is a quick check: $t_{1/2} = RC \ln 2 = 6.9 \text{ s}$, and the table shows V falling from 6.00 V to about 3.0 V in that time.

Labs that keep coming back

Parallel-plate capacitor – measure C with a capacitance meter as the plate separation d changes: C against $1/d$ is a line of slope $\epsilon_0 A$. Keep the plates parallel with spacers of known thickness

Equipotential mapping – two electrodes on conducting paper and a voltmeter probe; trace lines of equal V, then draw field lines perpendicular to them. The field strength is the potential difference between neighbouring lines divided by their spacing

Field inside a solenoid – a magnetic field sensor on the axis, at the center; B against current I is a line of slope $\mu_0 n$, with n the turns per meter. Zero the sensor first to remove Earth's field

Faraday's law – drop a magnet through a coil connected to a voltage sensor; the area under the emf-time graph is the change in flux linkage $N\Delta\Phi$, the same for every drop height. The peak emf grows with speed

RL circuit RL – the current after switching on approaches V/R ; plotting $\ln(1 - I/I_{\max})$ against t gives a line of slope $-R/L$

Resistivity and internal resistance – terminal voltage against current for a battery is a line of slope $-r$ and intercept the emf; R against L/A for a wire has slope ρ

Circuits in the design – what earns the points

Draw the circuit, with the ammeter in series and the voltmeter in parallel across the element. Show the switch, and where the sensor connects.

Say what the meter does to the circuit: an ammeter adds a small resistance, a voltmeter draws a small current. Choose a resistance range where neither matters, and say so.

For a time-varying quantity, use a sensor and data logger, not a stopwatch and an analog meter. Human readings cannot follow a 10 s decay at enough points to make a graph.