NATIONAL
MATH + SCIENCE
INITIATIVE

AP PHYSICS 1

Laboratory and Experimental Design

Pre-Assessment Questions

Some quantities in physics can be measured directly. Others cannot; they must be calculated using an equation by plugging in other measured quantities. Each box below lists a physical quantity. For each one, first mark whether the quantity is "directly measurable" or "must be calculated". If the quantity is "directly measurable", say with what equipment. If not, say what quantities must be measured and what equation must be used. One of each type has been done as an example.

Distance ☒ Directly Measurable ☐ Must be calculated How: Use a meterstick.	**Time Interval** ☐ Directly Measurable ☐ Must be calculated How:	**Average Velocity** ☐ Directly Measurable ☒ Must be calculated How: Measure distance traveled and time interval of travel, then plug into $v_{avg} = D/t$.
Instantaneous Velocity ☐ Directly Measurable ☐ Must be calculated How:	**Acceleration** ☐ Directly Measurable ☐ Must be calculated How:	**Force** ☐ Directly Measurable ☐ Must be calculated How:
Kinetic Energy ☐ Directly Measurable ☐ Must be calculated How:	**Potential Energy** ☐ Directly Measurable ☐ Must be calculated How:	**Spring Constant** ☐ Directly Measurable ☐ Must be calculated How:

Every AP Physics 1 exam will include a long, high-value free response question that requires the student to outline a procedure in order to accomplish some purpose, answer some question, or test some claim. We call this the **Lab-Based Question**. After writing the procedure, the student is always asked to explain how the data taken is to be analyzed in order to address the purpose/question/claim.

Before we discuss the strategies for success on lab-based questions, let me relay to you an important message from people who have read responses to lab-based questions on previous exams:

> **Literally 95% to 99% of students write a procedure that is much more complicated than is necessary when trying to respond to lab-based questions. If you find yourself using high technology, doing something you saw on Mythbusters, or writing more than three sentences for your procedure, you are almost certainly making the question harder than it actually is.**
>
> **When you write an extremely complicated procedure, it drives us, the readers, crazy. We lose our grip on reality. We wake up in the middle of the night screaming for you, the student, to just write the simple, easy, obvious procedure.* Please don't overthink these problems—make it easy on yourself to write an easy on us to read.**

All lab based questions have at least these two parts: a "write a procedure" part and a "data analysis" part.

Write a Procedure

The procedure is where you say what you do during the experiment and what direct measurements are being made.

Say what you are going to do with the equipment. "Roll the cart down the incline." "Drop the ball from rest." "Hang mass on the spring." Very simple sentences that say what you are doing.

Say what you are going to measure, and with what equipment. "Use the stopwatch to time how long it takes for the cart to reach the bottom of the incline." "Use a meterstick to measure the height from which the ball was released." "Use a balance to measure the mass of the object."

NOTE: If you are given a list of equipment and asked to "check" which pieces of equipment you want to use, then you must say how each piece of equipment is being used somewhere in your procedure. If you check "meterstick", "ruler", and "tape measure" but then only measure lengths with the meterstick, you lose points.

If you do multiple trials, say whether the trials are different, and if so how. "Repeat for several trials varying the position on the ramp at which the cart is released." "Repeat, each trial dropping the ball from higher up." "Perform more trials with different amounts of mass."

NOTE: If you are asked to perform an experiment in order to establish a relationship (look for the word relationship or function as in "is a function of"), then you absolutely must explain that you are performing more trials and you must say what you are varying from one trial to the next. This is usually a no-brainer because the problem itself tells you what quantities to vary. If the problem wants you to experimentally "determine if current is a function of voltage", your procedure should measure voltage, measure current, and "repeat for several trials of different voltages, measuring the different currents".

Data Analysis

This is when you explain how to take the direct measurements and turn them into calculated measurements OR represent the direct measurements in a graph or table OR both.

Direct Measurements—You can measure these directly and discuss them in your "procedure".

Length or height (meterstick or ruler)	Angle (protractor)
Time interval (stopwatch or photogate)	Acceleration (accelerometer)
Mass or Weight (balance or scale)	Potential Difference (voltmeter)
Force (spring scale or force sensor)	Current (ammeter)

Calcualted Measurements—You have to calculate these using an equation, so discuss them in your "data analysis".

Velocity ($v = d/t$)	Grav. Pot. Energy ($U_g = mgy$)	Torque ($\tau = rF$)
Momentum ($p = mv$)	Spring Constant ($F = kx$)	Rotational Inertia ($I = \tau/\alpha$)
Kinetic Energy ($K = ½mv^2$)	Spring Pot. Energy ($U_s = ½kx^2$)	Frequency (reciprocal of period)

Your data analysis part should explain what calculated measurements are being made along with equations that can be plugged into.

If you are being asked to deal with a "relationship" or "as a function of", then you MUST talk about making a graph. Relationships are illustrated with graphs; be clear about what the two quantities being graphed are.

If you are being asked to determine whether a relationship is directly proportional, you MUST say that you are going to check whether the graph is a line through the origin. Directly proportional specifically means a line through the origin (not just a graph that increases).

Reducing Error

If you are being asked for a way to reduce error, you can try arguing any of the following. Not all of these are good to say all the time—use your best judgment to determine which of these error-reducing techniques is best for the situation you are given:

Use more precise equipment. For example, instead of timing with a stopwatch, you can time by taking a video on your phone and going through the video frame-by-frame to get a much more exact time (yes, you can talk about this on the AP exam).

Talk about trying to eliminate friction or air resistance. If something falls, say that you can "perform the experiment in a vacuum chamber to eliminate air resistance". If something moves or rolls along a track or over a table, you can claim that "lubricating the wheels will reduce the effects of friction."

Talk about performing more trials. If you perform more trials but don't vary anything, then say you will "take an average" after all the trials are done. If you perform more trials while varying some quantities, then say that you will add those additional data points to your graph.

F1. Student *A* purchases a rubber ball from a toy store. The student notices that, if the ball is allowed to bounce vertically on a horizontal floor, the ball rises to a lower height after each bounce. The student formulates three different hypotheses about the behavior of the ball as it bounces:

Hypothesis #1: The ratio of the magnitude of the ball's velocity after the bounce to the magnitude of the ball's velocity before the bounce is the same for all bounces.

Hypothesis #2: The ratio of the magnitude of the ball's momentum after the bounce to the magnitude of the ball's momentum before the bounce is the same for all bounces.

Hypothesis #3: The ratio of the ball's kinetic energy after the bounce to the ball's kinetic energy before the bounce is the same for all bounces.

(a) Student *B* suggests that all three hypotheses are equivalent. This means that the three hypotheses are either all true together or all false together, and that Student *A* need only show that one of the hypotheses is true. Using appropriate equations and relationships, show that Student *B* is correct.

(b) In the space below, outline a procedure that Student *A* can follow to make measurements that would test the validity of one of her hypotheses. Clearly explain how commonly-available equipment would be used to make the measurements.

(c) In the space below, create an example of a graph or table of the measurements indicated in part (b) that would show evidence that one of the students' hypotheses is correct. Be sure to label the table or graph with quantities including units.

Skip

(d) Suppose that the ball's mass is m and it's speed just before striking the ground is v.

i. The magnitude of the impulse applied by the ground to the ball when it bounces is J. Which of the following statements about the value of J is correct?

___ $0 < J < mv$ ___ $J = mv$ ___ $mv < J < 2mv$ ___ $J = 2mv$ ___ $2mv < J$

Explain your reasoning.

Skip

ii. The net amount of work done on the ball when it bounces is W. Which of the following describes W?

___ Negative ___ Zero ___ Positive

Explain your reasoning.

F2. A student learning to drive is practicing emergency stops in a large, flat parking lot free of obstructions. An emergency stop occurs when the driver suddenly fully applies the brakes to the car so that the car will stop in the shortest time and shortest distance that the car is capable. The student notices that the faster the car is moving upon applying the brakes, the greater the time required to stop, and the longer the distance the car travels while stopping. The student asks the following two questions:

(1) Is the time T that elapses while the car is stopping directly proportional to the car's initial speed v?
(2) Is the distance D that the car travels while it is stopping directly proportional to the car's initial speed v?

The student communicates his questions to his instructor, who is a professional driver. She volunteers to operate the car while the student makes measurements necessary to experimentally answer his two questions. The student's physics teacher gives him access to commonly available equipment for making measurements.

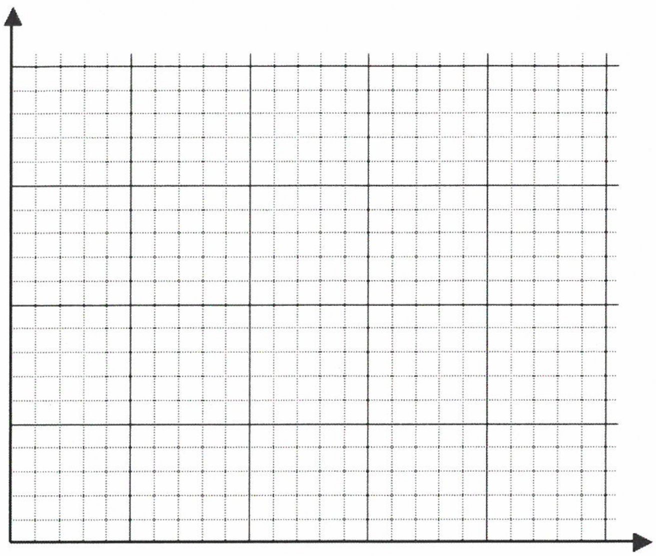
(a) In the space below, outline a procedure whereby the student can make the measurements necessary to answer his two questions. Be sure to explain how equipment will be used to make the measurements. Assume that the car has accurate, functioning gauges. Draw and label a diagram.

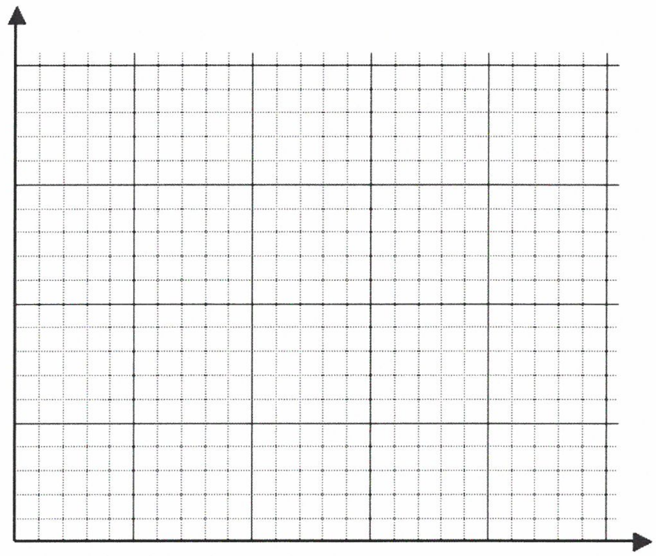
The student takes data for 11 trials. As the student and instructor performed trials over the course of the day, the weather changed from sunny and dry (☼) to wet and rainy (🌢) and then snowy and icy (❄). A table of the student's data is shown below, along with symbols that indicate the weather conditions at the time that particular trial was performed.

Trial Number	1	2	3	4	5	6	7	8	9	10	11
Weather Conditions	☼	🌢	❄	☼	☼	🌢	❄	☼	☼	🌢	❄
Initial Speed v (m/s)	10	10	10	15	20	20	20	25	30	30	30
Stopping Time T (s)	1.13	2.04	5.1	1.7	2.27	4.08	10.2	2.83	3.4	6.12	15.31
Stopping Distance D (m)	5.7	10.2	25.5	12.8	22.7	40.8	102	35.4	51	91.8	229.6

(b) i. Of the 11 trials shown in the table, which subset of the trials would be appropriate to graph in order to answer the student's two questions?

ii. On the grids below, plot two graphs of the trials you chose in part (b)-i. Each graph should be able to answer one of the student's two questions. Clearly label each axis with quantities and units, and put an appropriate scale on each axis. Draw a best fit line or curve on each graph.





(c) i. Give an answer to each of the student's two questions and justify each answer based on the shapes of the graphs you made.

F3. A student obtains a toy train car that can hold a quantity of sand and a length of toy train track. The student observes that the car rolls on the track with almost no friction. The student also observes that the train car slows down if sand from a stationary bucket empties into the car as the car rolls underneath the bucket. The student asks the following two questions:

(1) Does the train-and-sand system have the same momentum after pouring as the train has before pouring?
(2) Does the train-and-sand system have the same kinetic energy after pouring as the train has before pouring?

(a) Is it possible for the answer for both questions to be "yes"? Explain your answer using appropriate equations or relationships.

(b) The student wishes to perform an experiment to determine the answers to each of his questions.

i. In the space below, outline a procedure whereby the student can make the measurements necessary to answer his two questions. Explain how commonly-available equipment is to be used to make the measurements. Include a labeled diagram.

ii. Explain how the measurements made can be used to answer each of the two questions.