AP Physics Lab #2: Exploring Accelerated Motion (Big Ideas 3 & 4)

3.A.1.1: The student is able to express the motion of an object using narrative, mathematical, and graphical representations.

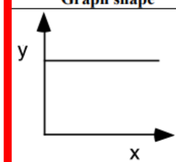
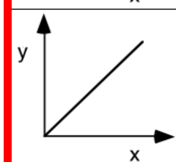
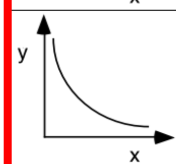
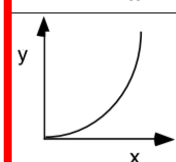
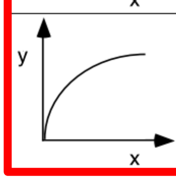
4.A.2.1: The student is able to make predictions about the motion of a system based on the fact that acceleration is equal to the change in velocity per unit time, and velocity is equal to the change in position per unit time.

This three-part activity will use three different methods to experimentally determine the acceleration due to gravity. It will have three questions and corresponding claims.

Exploring Accelerated Motion Pre-Lab:

Galileo studied the acceleration due to gravity by rolling spheres down an inclined plane. He studied the displacement versus time and the time versus displacement and deduced that the distances (d) traversed by a sphere down the incline are proportional to the square of time: $d \propto t^2$. Furthermore, he found that the time it took an object to roll down an incline was independent of its mass, thus proving his belief that all bodies do indeed fall at the same rate. In this case, the rate is the change in velocity.

Experimental data may be used to make predictions if you can determine a pattern or the relationship in the data. One way of determining a relationship is to plot a graph of the data. The resulting graph will give you an idea how two variables are related to one another. Most of the relationships encountered in AP Physics are linear, parabolic, or inverse. Please click here to view the graphical methods summary hand-out. The diagram to the right also shows these relationships and how to "linearize" the data. Linearizing data involves modifying the data so that it may be plotted as a straight line. In AP Physics you will need to linearize data with a best-fit line to determine the slope, which is often significant

Graph shape	Written relationship	Modification required to linearize graph
	As x increases, y remains the same. There is no relationship between the variables. (linear function)	None
	As x increases, y increases proportionally. Y is directly proportional to x. (linear function) Ex. F=ma, V=IR	None
	As x increases, y decreases. Y is inversely proportional to x. (rational function) $F = \frac{Gm_1m_2}{r^2}$ Ex. a = F/m $F = \frac{kq_1q_2}{r^2}$	Graph, y vs. $\frac{1}{x}$ Or y vs. x^{-1} Or y vs. $1/x^2$
	Y is proportional to the square of x. (polynomial function) Ex. $x = \frac{1}{2} at^2$, $x = v_0t + \frac{1}{2} at^2$, KE=1/2 mv^2	Graph y vs x^2
	The square of y is proportional to x. (radical function) Ex. $T_p = \sqrt{\ell}$, $v = \sqrt{F_t}$	Graph y^2 vs x Or y vs $\sqrt{x}$

P1. Graph the data below for an object in free-fall. Remember that all graphs should be at least ¾ of a page with labeled axes.

Y axis (position; m)	X axis (time; s)
0.1	0.14
0.5	0.32
1.0	0.46
1.7	0.59
2.0	0.63

P2. Create additional graphs until you have linearized the data. Include the equation for the line on your graph and using the slope, determine the acceleration due to gravity for the object.

The acceleration of an object may be calculated by analyzing the displacement versus time data of a moving object. To do so, you must first calculate the change in velocity between each x versus t data point. Where the $v = \Delta x/\Delta t$. The acceleration of an object is equal to the change in velocity per unit of time: $a = \Delta v/\Delta t$.

Exploring Accelerated Motion Lab:

Materials: Various objects that will be dropped, 6' U-channel, 3 finger ring clamp, tall ring stand, measuring tape, stopwatch (phone), Hudl Technique (optional), Video Physics (optional), steel ball, glass marble, block of wood, meter stick, Vernier motion sensor probe, LabQuest 2, LoggerPro (optional), 10" rod, tennis ball

Please make sure you have reviewed the *Uncertainties and Significant Figures Hand-out* (click here) prior to collecting and analyzing data for this lab. Throughout this course you will also need to determine how many trials to perform. This will be your choice, but I recommend you replicate trials until your values are nearly the same. From those data, it is probable that your average will be accurate.

In this course, we will use various digital probes to collect data using the LabQuest 2 interface and optional Logger Pro software. In this investigation, you will use a motion sensor that emits a continuous stream of ultrasonic beeps. Ultrasonic means that the frequency (pitch) of the beeps is just above audible sound that you can hear. If the stream of beeps is pointed at an object, the waves reflect off the object and return to the sensor. The sensor uses the fact that sound waves travel at a constant speed of 343 m/s, which can be used with the fact that $v = \Delta x/\Delta t$ to calculate the distance. Since the beeps are emitted at a fast rate (10 to 100 times a second; 10-100 Hertz) the motion sensor can also keep track of an object's change in position with respect to time.

Part 1: Investigating Objects in Free-Fall:

Ask a Question: *How can I experimentally determine the acceleration due to gravity?*

Q1. Observe the objects you will be dropping. Make some predictions for the rate of fall for the objects. What could possibly hinder the objects' fall? What could possibly assist the objects' fall?

Q2. Make a sketch of the position as a function of time of an object being dropped. Recall that according to the College Board's course description, a sketched graph means to "draw a graph that illustrates key trends in a particular relationship, such as slope, curvature, intercept(s), or asymptote(s). Numerical scaling or specific data points are not required in a sketch."

The class will identify a location(s) to conduct the trials. On a nice day, we may even foray out to the stadium, or conduct trials in the stairwell by the elevator. Regardless of the location, you will need to measure the vertical height of the drop area. Remember in physics, we will use base SI units.

Q3. Research your question. Create a data table suitable for this part of the investigation and collect all of your data for the objects. It is acceptable to use video analysis to ensure accurate times.

Q4. Use your data to calculate the acceleration due to gravity (g). Be sure to show all work and include units.

College Board prefers students use 10 m/s^2 for calculations on the AP Physics 1 exam. I will mention this throughout the course; however, I prefer to use $g = 9.81\ m/s^2$ when we are conducting lab investigations. So please get in the habit of using 10 m/s^2 on all problem sets and exams and use 9.81 m/s^2 for labs.

Q5. Calculate the percent error of your data.

Q6. Gather the value of "g" determined by at least five other groups in the class. Calculate the percent difference between your results compared to the class average. Make your claim.

Part 2: Investigating Acceleration on an Incline:

Ask a Question: *How can I experimentally and graphically determine the acceleration of a ball down an inclined plane?*

Q7. How do you expect the ball to roll down the incline? Make some predictions of this object's motion compared to the object in free fall. As the ball rolls down the incline, will it have the same displacement every second? Please justify your response using semi-quantitative reasoning.

The figure below (figure 1) shows the general set-up for Part 2. Using the 3-finger clamp, secure the U-channel to a ring stand. The incline should be arranged with the 20-cm near the bottom of the incline. Please double check to ensure the increments are indeed 20-cm apart. If not, use some rubbing alcohol to remove any extraneous and erroneous marks and re-measure the increments. Adjust the incline to approximately 30° using the level app on your phone. Place a block of wood at the end of the incline to stop the ball at the bottom. For this part of the lab, you will use a steel ball of your choice.

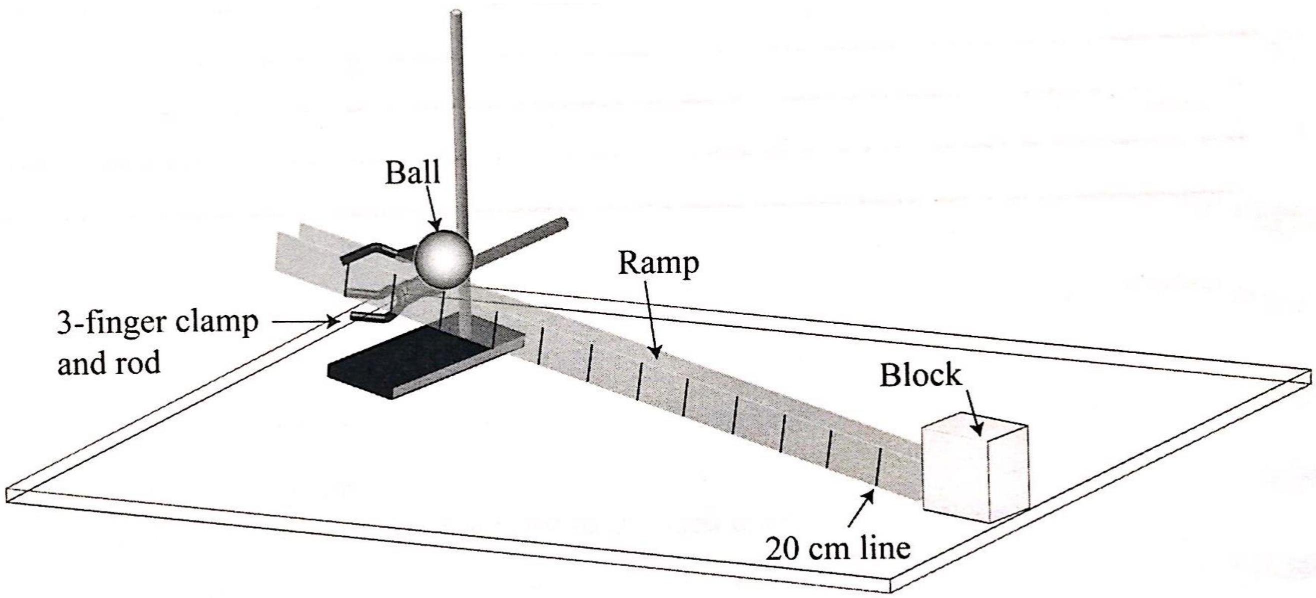


Figure 1

Q8. Research your question. You will need to create a data table suitable for determining the amount of time it takes for the steel ball to roll a distance of 20.0 cm down the incline. Repeat numerous trials until you have obtained a convincing average time. Also, repeat this process every 20-cm up to the full length of the U-channel. Please take a moment to read ahead to determine your data table layout.

Q9. Plot a graph of the distance as a function of time. Under the graph, write a brief description of the significance of the trend indicated by the data.

Q10. Plot a second graph that linearizes the data using a best-fit line. Also include the equation of the line.

Q11. What is the significance of the slope of your graph from question 10?

Q12. Next, you will roll a glass marble of your choice down the incline, set at the same angle, using the same method as with the steel ball. Organize your data into a suitable table.

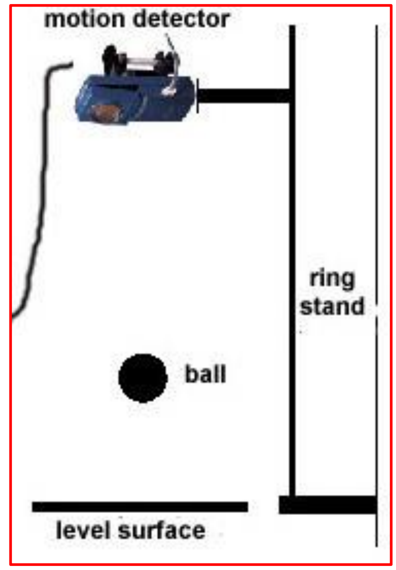
Q13. Based on your observations of the steel ball versus the marble, what can you conclude? Please consider both the mass and the diameter of the balls in your answer.

Q14. What if you raised the incline and repeated the experiment? What should happen? What if you kept raising the incline? What would eventually happen? If you are not sure about your answer, then just try it.

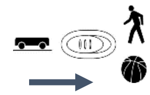
Make your claim.

Part 3: Sensing Acceleration:

Aask a **Question:** *How can I use a digital motion sensor to measure the displacement and time of a ball in free fall to calculate the acceleration due to gravity (g)?*



Research your question. Using a ring stand and appropriate clamps, attach a motion probe to a tall ring stand that hangs over the floor. Make sure the probe is mostly level and that there is a substantial overhand from the bench to ensure the sound waves do not reflect off the bench. Also, you want to make sure the waves are not reflecting off your shoes, chairs, or any other nearby objects. You may need to use a counterweight or clamp to prevent the ring stand from angularly accelerating off the bend top. You may need to adjust the switch on the probe to the ball/person setting as shown in the diagram to the right. Have one partner hold a tennis ball near the sensor. Meanwhile a second partner can activate the software to begin collecting data. After a couple seconds of data collection, drop the ball and stop collection once it hits the floor. Expect to have several trials before you perfect the technique needed to collect accurate data.



Q15. Examine the graph displayed on the LabQuest unit, which should be curved (i.e., quadratic). Zoom in on the curve and transfer ten data pairs to a suitable table. The graph should be similar to your "sketch" in Q2.

Q16. Use the data above to calculate the acceleration due to gravity. As always, show all of your work. Calculate the percent error using 9.81 m/s^2 as your accepted value. Make your claim.

Summarize your data, conclusions, and any modifications you would make to future investigations. Your conclusion should show how or why the data are relevant and support your three claims. You should justify why the evidence is important to the claims. Your conclusion should always indicate the relationship to one or more scientific or math principles (i.e., Georgia Standards of Excellence and College Board Learning Objectives).

Please self-assess your lab report using the rubric/checklist.