PHSC 2105 Acceleration of a Freely-Falling Body Name:______________________

Object: To study the motion of a freely-falling body, including to measure its acceleration by two different methods.

Introduction: The law of falling bodies says that all objects in free fall (motion under the influence of gravity only) have the same acceleration; near the surface of the earth it has a value of a_g, usually simply called g. Use $a_g = g = 9.80\,\mathrm{m/s^2} = 980\,\mathrm{cm/s^2}$ as the accepted value in this lab.

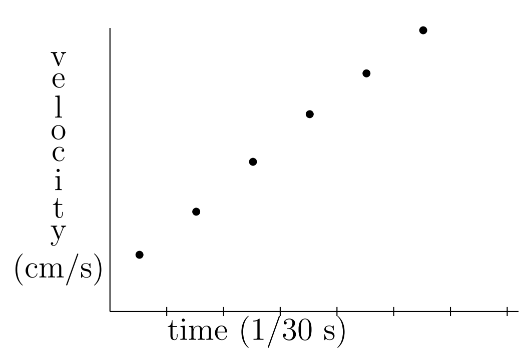
Method 1: Behr Apparatus: This apparatus uses a fast timing mechanism to observe a cylinder with a metal ring as it falls freely under the influence of gravity (air resistance is negligible). A high voltage between a vertical wire and a pipe causes a spark to jump every 1/30 second. The spark passes through the falling cylinder and then through the special paper tape, making a small dot on the tape, thus marking the position of the falling cylinder at each 1/30 second.

Procedure:

1. Level the apparatus. Verify levelness by dropping the cylinder in a dry run with no sparks.
2. Start the sparker, release the cylinder, and then release the sparker button after the cylinder has landed, all in quick succession.
3. Tear off the paper tape after the last dot.

Analysis:

1. Call the first *good* dot time zero and location zero (you may not want to use the very first dot). Then record in a table the positions (in cm) for the rest of the dots relative to *that* dot.
2. Subtract successive positions in pairs to obtain the displacements for the Δy column in the table. Verify the Δy by measuring between successive dots with a ruler. Then divide each Δy by Δt (which is 1/30 s) to obtain the average velocity for each time interval (*i.e.*, between successive dots).
3. Subtract successive velocities in pairs to obtain the information for the Δv_y column in your table. Then divide each Δv_y by Δt to obtain the acceleration for each interval (*i.e.*, between successive velocities). Compute the average of all of the numbers in the acceleration column.
4. Make a graph of velocity versus time. The value on the vertical axis for each data point is the average velocity (acquired from your table) during that time interval. The value on the horizontal axis is halfway between the tic marks representing the times 1/30 s apart, because the dot represents the *average* velocity during the whole interval. See example. Use a whole page. (We are using an unusual coordinate system where we're calling down positive.)

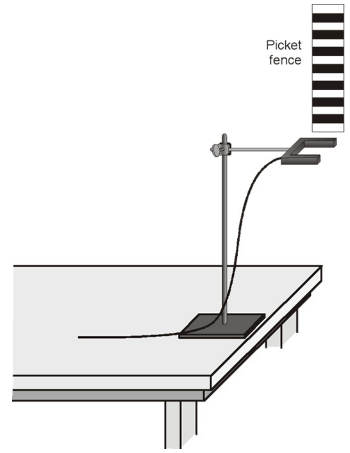


5. Draw a best-fit straight line between the points on the graph and compute its slope and read the intercept off the v axis. Think of $v = at + v_0$ in terms of $y = mx + b$; the slope of your line will be a and the intercept will be v_0.
6. (a) Did your straight line in Step 5 above go through the origin? Why or why not?
   (b) What value of acceleration did you compute from the slope of this line?
7. Draw the acceleration vs. time graph (*i.e.*, the slope of the velocity graph). Use a half page.
8. What do you expect a graph of position versus time to look like? Make a graph of position vs. time using the first two columns of your table as your data. Draw a best-fit smooth curve through the data points. Use a half page. Is the shape of the curve what you expected?
9. Compute the percent difference between each of your two measured values of g (the slope of the line and the average from the table) and the accepted value of $g = 980\,\mathrm{cm/s^2}$.
10. On the graph of position vs. time also plot the theoretical curve of $x = v_0 t + \frac{1}{2}at^2$ using values of v_0 and a obtained from Step 5 of the analysis. How does this theoretical curve compare with the experimental one?

Graphing Summary: Summarize what you have learned by graphing on stacked graphs on the same page all three quantities for an object thrown straight up in free fall. Make the horizontal time axes parallel so the times line up for the three graphs. Draw them in order: position, velocity, and acceleration from top to bottom, so that each graph is the slope of the graph above it. Make these modifications from your earlier graphs: use units of m instead of cm, round g to $10\,\mathrm{m/s^2}$, and (whereas you previously called down positive) call up positive, and, as mentioned, the object is thrown up ($v_0 = 30\,\mathrm{m/s}$) instead of released from rest.

Questions about Free Fall:

1. If an object were thrown straight up in a vacuum
   (a) would it be in free fall (neglecting air resistance)?
   (b) what would its acceleration be on the way up (both magnitude and direction)?
   (c) what would its acceleration be at the tippy top (both magnitude and direction)?
2. In another experiment a body falling straight down has a speed of $3.00\,\mathrm{m/s}$ at one instant.
   (a) Compute its speed $0.50\,\mathrm{s}$ later.
   (b) Compute the distance it would fall during this $0.50\,\mathrm{s}$.



Method 2: LabQuest and Picket Fence: Use the LabQuest and photogate sensor. The photogate has a beam of infrared light that travels from one side to the other. It can detect whenever this beam is blocked. The piece of clear plastic with evenly spaced black bars on it is called a picket fence. As the picket fence passes through the photogate, the LabQuest will measure the time from the leading edge of one bar blocking the beam until the leading edge of the next bar blocks the beam. This timing continues as all eight bars pass through the photogate. From these measured times, the LabQuest will calculate the velocities and accelerations for this motion and graphs will be displayed.

Procedure:

1. Set up the LabQuest and photogate appatus as shown in the figure. Click on photogate mode and tell it to use the picket fence. Select the little graphing icon at the top of the LabQuest screen. Graph only the velocity by selecting it on the left.
2. Press the "play" button in the bottom left-hand corner and then drop the picket fence through the photogate. Make sure the picket fence is completely vertical, doesn't twist, and doesn't touch the apparatus. Have the picket fence land on something very soft or have a groupmate catch it.
3. The slope of your velocity graph is the best-fit acceleration for this trial. Find this by going to the Analyze menu then down to Curve Fit. Select "linear." Record the slope as your acceleration in a table. (Note that you are looking for the slope of a velocity vs. time graph, just as in the other method.)
4. Repeat Procedures 2–3 five more times. Average the results and compare to the accepted value.

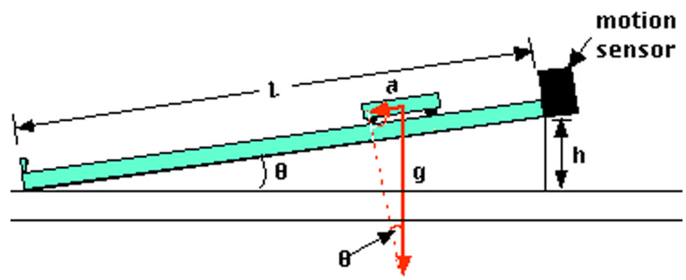
Extensions:

1. Would dropping the picket fence from higher above the photogate change any of the variables you measured? Try it.
2. Would throwing the picket fence downward, but letting go before it enters the photogate change your measurements? How about throwing the picket fence upward? Try it.
3. How would adding air resistance change the results? Try adding a loop of clear tape to the upper end of the picket fence to act as a parachute. Drop the modified picket fence through the photogate and compare the results with your original free fall results.

Conclusions: On your lab report write about what you learned about the law of falling bodies, and the relationship between position, velocity, and acceleration. Especially talk about the significance of the slope of straight lines. Add conclusions about the lab equipment and techniques.

Method 3: LabQuest and Motion Detector:

In the early seventeenth century Galileo thought about the motion of falling objects. He knew they sped up, but exactly how? Objects in free fall move quickly and Galileo only had crude methods to measure time intervals, such as pendulums and water clocks; so he slowed the motion down by rolling balls down inclined planes.



Theory: We will soon learn Newton's second law: $a = F_{\text{net}}/m$. The net force on the cart is $mg\sin\theta$. Combine the two, cancel the m, and note that $\sin\theta = \text{opp}/\text{hyp}$.

$$a = g\sin\theta = g\,\frac{h}{L} \tag{1}$$

Procedure:

1. Set up the cart on the track with the motion encoder receiver on the uphill side of the track. Find $\sin\theta$ using basic trigonometry by measuring the hypotenuse of the track and the rise of the high end. Start with a small angle.

2. Turn on the motion encoder cart. Ensure that it and the motion encoder receiver are working by sliding the cart up and down the track noting the changes in distance to the receiver on the LabQuest2.

3. Push "play" on the LabQuest2 and let the cart slide down the track. Have it hit something soft at the end. A graph of the velocity should appear in the LabQuest2 window. Select the best portion of the graph by dragging the stylus across the screen.

4. Find the slope of this graph in the Analyze menu. Go to "curve fit," choose "velocity," and choose "linear fit" in the dropdown box. The slope labeled m is the acceleration.

5. Repeat Procedures 3 and 4 a couple of times and average the results.

6. Repeat Procedures 1–5 five or six more times raising the end of the track a bit more each time.

7. Turn off the motion encoder cart.

Analysis: Think of equation 1 in terms of $y = mx + b$. Make a graph of acceleration vs. $\sin\theta$; compare the best-fit slope to the value of g (or a_g) for Ephraim.

Conclusions: Compare the educational value of the three methods. Which is most accurate, and why? How does modern technology help physicists learn new physical laws? How does modern technology help physics students learn physics? Elaborate on your own conclusions.