Physics 2010  Motion with Constant Acceleration  Experiment 1

In this lab, we will study the motion of a glider as it accelerates downhill on a tilted air track. The glider is supported over the air track by a cushion of air and can move along the track with almost no friction. There is some air resistance as the glider moves, but this is relatively small. We will verify the following two equations of motion for constant acceleration in one dimension:

\[ x = x_0 + v_0 t + \frac{1}{2} at^2 \]  
\[ v = v_0 + at \]

where \( x \) = position, \( v \) = velocity, \( t \) = time, \( a \) = acceleration, \( x_0 \) = initial position, and \( v_0 \) = initial velocity.

A word of caution. The air tracks are expensive and easily damaged so please treat them gently. Do not place the gliders on the track unless the air supply is on, since the gliders can scratch the track. Remove the gliders from the track before making any adjustments to the gliders. The gliders are very easily damaged if dropped.

**Begin by leveling the track.** With the air on, place a glider on the track, and adjust the track’s feet until the glider can remain stationary on the track, not sliding one way or the other. Then incline the track a precise amount, by placing one of the wooden blocks under the foot of the air track on one side. As shown below, \( h \) equals the height of the block.

\[ \sin \theta = \frac{h}{L} \]

\[ \theta = \sin^{-1} \left( \frac{h}{L} \right) \]

The track is now inclined by an angle \( \theta \), where \( \theta = \sin^{-1}(h/L) \).

The acceleration of gravity is \( g = 9.80 \text{ m/s}^2 \), and the direction of this acceleration is straight down. The *component* of this acceleration along the direction of the track is
\[ a = g \sin(\theta) . \]  

(You may not have covered this yet in lecture, but for now, just notice that when \( \theta \to 0 \), \( a \to 0 \) and when \( \theta \to 90^\circ \), \( a \to g \), as you would expect.)

Measure \( h \), \( L \), and compute \( a = g \sin \theta = g \frac{h}{L} \). Note that you do not have to compute \( \theta \) in degrees. You only need \( \sin(\theta) \) and that equals \( h/L \). *Don't forget units!* 

The speed of the glider on the track will be measured with photogate timers. A card 10.0cm long, placed on top of the glider interrupts a light beam in the photogate and triggers a timer. The photogate timer can be used to measure either the time for the glider to travel between two gates (when the timer control is set to PULSE mode) or the time for the card to pass through one gate (when set to GATE mode). The timer can be set to read either milliseconds (msec) or 0.1 msec. With 0.1 msec resolution, the timer will count up to a maximum of 2 sec, before overflow.

Place the two photogates over the air track so that they are a meter or more apart and at least 20 cm from each end of the track.

**Part 1. Test of \( x = x_0 + v_0 t + \frac{1}{2} a t^2 \)**

In this experiment, we will release the glider from rest very close to the first photogate so that the initial velocity \( v_0 = 0 \).

1. Measure the distance \( (x-x_0) \) between the two photogates. This can be done most precisely by moving the glider along the track to see exactly where the photogate is triggered (a red LED on the photogate lights up) and noting the position of the glider with the ruler on the side of the track.
2. Set the timer to PULSE mode and msec (not 0.1msec). Press the RESET button on the timer to clear the clock and ready the photogate. Hold the glider stationary as close as possible to the first gate, without triggering the timer, and then gently release it, without giving it any push. Record the time \( t \) to pass between the two gates. Repeat several times to get an average value of \( t \) and an estimate of the uncertainty in \( t \). Roughly, \( \delta t \equiv (t_{\text{max}} - t_{\text{min}})/2 \). Now compute
\[
a = 2 \frac{(x - x_o)}{t^2}
\]

Compare this \(a\) with your earlier \(a=gh/L\). Do the two values of \(a\) agree within significant figures? Can you think of any sources of error we have not taken account of?

**Part 2. Test of \(v = v_o + at\)**

In this part, unlike in Part 1, we will not assume that \(v_o = 0\). We will release the glider from a point uphill of the first photogate, so that the glider has some velocity \(v_o > 0\) when it passes through the first photogate. Its final velocity when it passes through the second photogate is \(v\).

Throughout this part, it is important not to move the photogates from their original positions. Otherwise, you will not be able to compare data taken at different times and you will have to repeat some data-taking. As usual, do a rough error analysis by keeping track of significant figures. We will assume that the uncertainty is about \(\pm 1\) in the last place, so don't include useless extra digits just because they come out of your calculator.

With the timer in GATE mode, it will read the time \(\Delta t_1\) that the card was in gate 1. The card has a length \(\Delta x \equiv 10.0\) cm, so the average velocity of the glider in gate 1 is \(\frac{\Delta x}{\Delta t_1}\). When the READ switch is toggled, the timer displays the total time spent in both gates 1 and 2 (= \(\Delta t_1 + \Delta t_2\)). So, to get \(\Delta t_1\) and \(\Delta t_2\), follow this procedure: RESET the timer. Release the glider from a known point uphill of gate 1. Stop the glider after it passes gate 2. Read \(\Delta t_1\) from the timer. Toggle the READ switch and read \(\Delta t_1 + \Delta t_2\). Compute \(\Delta t_2\) by taking the difference of the two readings.

Repeat several times, always releasing the glider from the same initial position, to get good average values for \(\Delta t_1\) and \(\Delta t_2\). Now compute \(v_{\text{initial}} = v_o = \frac{\Delta x}{\Delta t_1}\) and \(v_{\text{final}} = v = \frac{\Delta x}{\Delta t_2}\).

Now we must measure the time interval \(\Delta t\) that the glider spent between the gates. (This time interval \(\Delta t\) is the \(t\) in the equation \(v = v_o + a \cdot t\).) Set the timer to PULSE mode, hit RESET, release the glider from the same initial point, and record the displayed time. Unfortunately, this displayed time is not quite the same as the time \(\Delta t\) that we want. The displayed time interval \(\Delta t'\) (read "delta-t-prime") is the interval between the times when the leading edge of the card hit the photogates. What we really want is the interval \(\Delta t\) between the times when the center-of-mass of the glider passes through the gates. So we need to know the times when the glider was half-way through the gates.
Let's say $t_1'$ = time when leading edge of card hit gate 1 and $t_2'$ = time when leading edge of card hit gate 2. The time interval $\Delta t$ that we want is

$$
\Delta t = t_{\text{final}} - t_{\text{initial}} = \left( t_2' + \frac{\Delta t_2}{2} \right) - \left( t_1' + \frac{\Delta t_1}{2} \right) = \left( t_2' - t_1' \right) + \frac{1}{2} (\Delta t_2 - \Delta t_1) = \Delta t' + \frac{1}{2} (\Delta t_2 - \Delta t_1)
$$

Make several measurements of $\Delta t'$ to get a good average, and then compute

$$
\Delta t = \Delta t' + \frac{1}{2} (\Delta t_2 - \Delta t_1). \text{ Finally compute the acceleration from}
$$

$$
a = \frac{\Delta v}{\Delta t} = \frac{\frac{\Delta x}{\Delta t_2} - \frac{\Delta x}{\Delta t_1}}{\Delta t' + \frac{1}{2} (\Delta t_2 - \Delta t_1)}
$$

Compare your three values of $a$, $a_0 = gh/L$ (from Part 0), $a_1$ (from part 1), and $a_2$ (from part 2).
To be handed in at the *beginning* of your laboratory period:

1. If the air track is inclined by an angle $\theta = 7^0$, what is the acceleration "a" along the track, from equation (3)? (Don't forget units, and sig. figs!)

2. Solve the following equation for $a$.

   $$x = x_o + v_o t + \frac{1}{2} at^2, \quad a = ?$$

3. Explain what the photogate timer measures when it is in PULSE mode. Explain the GATE mode.

4. Explain the function of the READ switch on the photogate timers.

5. In part 2 of the lab, a time interval $\Delta t'$ (t-prime) and a time interval $\Delta t$ (no prime) are described. Describe in words the difference between these two times.

6. Dry Lab (next page.)
"Dry" Lab Report.

For this lab, and all other labs in this course, we ask you to think carefully about what variables you will measure, what variables you will compute, and how you will display this information in your report.

Write out a "dry" lab report, that is, a report with no actual data, but which contains all the variables you will measure directly and all the variables that you will compute. The report should show the approximate format of the actual lab report, including tables and calculations. In this dry lab, give the symbols for all measured variables and a short description, in words, of the variables. For computed variables, give the equation for the variable and a short description of the variable, unless it was defined previously. For tables, give the column headings and show the general layout of the table.

There is more than one way to write a dry lab report. In general, it should show the variables, tables, and calculations in the same order that they will be done during the actual lab. Strive for a clear, clean, layout that the reader can follow easily. If a graph is called for in the lab, the dry lab should show a graph title, axes that are properly labeled, and a rough sketch of the expected shape of the graph.

We suggest that you make an extra copy of your dry lab, so that you can hand one copy in at the beginning of the lab, and use the other as a template for preparing your actual report during the lab.

Here is an example of a dry lab report. Suppose that the lab instructions describe an experiment in which the student measures the acceleration of gravity g by timing the fall of a marble over a measured distance L. g is then computed from the equation $L = \frac{1}{2}gt^2$. Two different lengths L are chosen and several measurements of t are made for each value of L. The average value of g is then compared with the known value, $g = 9.80\text{m/s}^2$. The dry lab for this part of the experiment might appear as follows:
Part 1: Determination of the acceleration of gravity \( g \).

\( t = \) time of fall of marble

\( L = \) distance of fall of marble

**Determination 1**

\[ L_1 = \ldots \]

<table>
<thead>
<tr>
<th>trial</th>
<th>t(sec)</th>
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<tbody>
<tr>
<td>1</td>
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\[ g_1 = \frac{2L_1}{t_{avg}^2} = \ldots \]

**Determination 2.**

\[ L_2 = \ldots \]

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<thead>
<tr>
<th>trial</th>
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\[ g_2 = \frac{2L_2}{t_{avg}^2} = \ldots \]

**Comparison with \( g_{\text{known}} \).**

\[ g_{avg} = \frac{g_1 + g_2}{2} = \ldots \quad g_{\text{known}} = 9.80 \text{ m/s}^2 \quad \% \text{ discrepancy} = \left| \frac{g_{\text{known}} - g_{avg}}{g_{\text{known}}} \right| = \ldots \]