Physics Lab 6: Marble-ous! Motion in 2 Dimensions

Goals: Improve communication and teamwork capacities**;** Improve ability to make careful measurements; Use constant acceleration kinematics equations and independence of perpendicular motion to **m**odel a **m**arble's **m**otion in **m**ore than one di**m**ension.

Equipment: You will be oriented to the location and proper use of the equipment for this lab. At the end of the session, return the equipment to its original configuration and location.

Groups & Lab Notebook: For today's investigation, you will work in groups of 2; your instructor will facilitate pair formation. Update your Table of Contents. General Lab Notes guidelines apply.

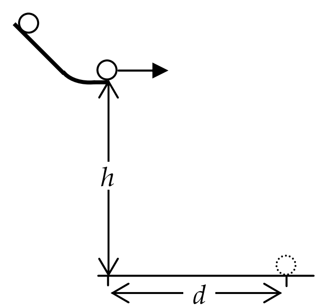
Constant acceleration formulas:

$x = x_0 + v_{0x}t + \frac{1}{2}a_x t^2 \Rightarrow \Delta x = v_{0x}t + \frac{1}{2}a_x t^2$	$y = y_0 + v_{0y}t + \frac{1}{2}a_y t^2 \Rightarrow \Delta y = v_{0y}t + \frac{1}{2}a_y t^2$
$v_x = v_{0x} + a_x t \Rightarrow \Delta v_x = a_x t$	$v_y = v_{0y} + a_y t \Rightarrow \Delta v_y = a_y t$
$(v_x)^2 = (v_{0x})^2 + 2a_x\Delta x$	$(v_y)^2 = (v_{0y})^2 + 2a_y\Delta y$

Special case: projectile motion → constant velocity in horizontal direction, constant acceleration in vertical direction (due to gravity), standard coordinate system

$a_x = 0$	$a_y = -g = -9.8\ \text{m/s}^2$
$v_x = v_{0x}$	$y = y_0 + v_{0y}t - \frac{1}{2}gt^2 \Rightarrow \Delta y = v_{0y}t - \frac{1}{2}gt^2$
$x = x_0 + v_{0x}t \Rightarrow \Delta x = v_{0x}t$	$v_y = v_{0y} - gt \Rightarrow \Delta v_y = -gt$

Part 1: Getting Started



a) Gather your equipment and assemble it as described.
b) Draw a sketch of your apparatus (similar to that shown) in your lab notebook.
c) Determine a release point on the ramp so that when the marble falls a vertical distance h of about 0.30 m, it travels a horizontal distance d of about 0.20 m. Setting these exact distances is not critical, though careful measurements of the actual distances will be. Always release the marble from rest from that point on the ramp.
d) Practice your release technique. With good release technique, the impact locations from the same height h and the same release point on the ramp will be almost identical.
e) Measure h and d as carefully as possible. Record these results. You will use them in Part 3: Launch speed of marble.

Part 2: Making Measurements

a) Set h and measure d for as many of the following as you can. It is not critical that you set h exactly, but it is critical that you measure the h you actually use.
b) Start with the high measurements first. You might not be able to get the largest suggested heights (that depends on your particular ring stand). The lowest suggested heights might be difficult to measure; that's ok.
c) Copy the table into your lab notebook (you may want to use column form instead of row form; we use row form here to save room). Fill it out with your measurements. You already have one set of measurements from Part 1.

approximate h (m)	0	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60
measured h (m)	0												
measured d (m)	0												

d) Due to our choice of coordinate system, the measured d is the x position of the impact location, while the y position of the impact location is actually $-h$. You will address this in a later part, but for now just use this to fill out the following table for the (x, y) coordinates of the impact location. Copy this table into your lab notebook (again, you may prefer column format).

$x = d$ (m)													
$y = -h$ (m)													

e) Launch LoggerPro, and type in your table entries. The program should automatically plot those points as well as rescale the axes to show you all the points. Note that in contrast to graphs we have frequently constructed, this is not a position vs. time graph: this is a *y* vs. *x* graph.

f) Highlight the points, and fit a quadratic (you may need to change the horizontal scaling so that it starts a little before $x = 0$ and goes a little after your largest x value in order to highlight all the points). Write down the best fit quadratic function using the fit values for A, B, and C. Save this graph for inclusion in your lab notebook.

Part 3: Launch speed of marble

a) Use the results of your (approximately) 0.30 m height measurements from Part 1. For convenience, we set the origin to be at the location where the marble leaves the ramp.
b) Since you have launched the marble horizontally, what is v_{0y}, the initial velocity in the vertical direction? Here, initial means just when the marble is launched/leaves the ramp; we'll also call this the launch velocity.
c) Show that $y = y_0 + v_{0y}t - \frac{1}{2}gt^2$ simplifies to $y = -\frac{1}{2}gt^2$ in this case. Recall that we set the origin to be at the location where the marble leaves the ramp.
d) Why does $y = -h$ (in other words, why is y a negative number)? Explain both in terms of the choice of coordinate system (what did you call your origin?) and also in terms of the equation $y = -\frac{1}{2}gt^2$ (what happens mathematically if y is a positive number?)
e) Since $y = -h$ and you have measured h and $y = -\frac{1}{2}gt^2$ where g = 9.8 m/s^2, you can solve for t, the time it takes the marble to fall from the ramp to the ground (table). Determine t.
f) In this model, the acceleration in the vertical direction was constant. What constant was it? Why? What assumptions were made?
g) In this model, the acceleration in the horizontal direction is zero. What assumptions were made? Why does this mean that the horizontal velocity is constant?
h) Since $a_x = 0$, the horizontal velocity is constant, and $\Delta x = v_{0x}t$, so $v_{0x} = \frac{\Delta x}{t}$. Explain why $\Delta x = d$ in this investigation. Now, use your measured $\Delta x = d$ and your calculated t to determine v_{0x}. Why would we call this the launch speed of the marble?
i) Pick a different h, d measurement from Part 2, and repeat the calculations of this section to determine the launch speed of the marble in that case.

Part 4: Predict an impact location

a) Set the height to be approximately 1.20 m above the ground (here we mean the actual lab floor). Measure the height h as carefully as possible.
b) Use your previously determined launch speed and the current height to calculate the horizontal distance the marble will travel before hitting a vertical surface. In other words, predict the impact location. Follow the same chain of reasoning as before: use the vertical direction to determine the time in the air (this will be the exact same calculation as before, except with your new h. Why?). Then, use $\Delta x = v_{0x}t$ with the same v_{0x} you have already calculated (why can you use this?).
c) With an instructor present, test your prediction.

(if time) Part 5: Land on target

a) You will be provided with an impact location.
b) Calculate the horizontal and vertical placement of the ramp required to land at the target location.
c) With an instructor present, show your stuff.

Implications

Though the investigation you have completed may not seem profound, the implications are. Let's consider several (some of these are perhaps more philosophical than others, but I encourage you to think about and discuss them all):

a) What does the fact that your predictions were correct mean about your assumption that the acceleration in the y-direction was 9.8 m/s^2 down? What does this mean for our assumption about neglecting air resistance?
b) What does the fact that your predictions were correct mean about your assumption that the acceleration in the x-direction was zero? What does this mean for our assumption about neglecting air resistance?
c) What does the fact that your predictions were correct mean about your assumption that the motion in perpendicular directions was independent?
d) What does the fact that your predictions were correct mean about the validity of your mathematical model?
e) What does it mean that a mathematical model can describe natural phenomena so carefully that you can effectively predict the future?