Name: ______________________

Partner(s): ______________________

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Date: ______________________

# Projectile Motion

## *1. Purpose:*

The purpose of this lab is to develop an understanding of two-dimensional kinematics and to recognize the increasing role of computer modeling as an important tool that supplements real experiments and theory in the world of science. The role of air resistance is also explored.

## *2. Introduction:*

At this point, you have experimentally investigated kinematics in one dimension using the air-track. You may have even studied two-dimensional kinematics in your lecture course. When it comes to introducing students to kinematics in dimensions higher than one, the prototypical situation favored by most texts and teachers is "projectile motion." While these experiments are best conducted on a football field or at a shooting range, that would be much too much fun to be legally allowed in a university course. As such, we do the throwing and shooting on a computer monitor. This has two distinct advantages. First, it gives accurate data (Huh?) with little effort. Second, one can conduct a wide range of experiments in a relatively short amount of time and study aspects of the problem, such as changing the acceleration due to gravity or the amount air friction that are not easily studied in the laboratory. This allows you to ***develop*** an intuitive and deeper understanding the problem.

## *3. Procedure:*

The simulation file "2DMotion.llb" should be located on the desktop of your computer. Double-click to open the simulation program. You should see a window similar to what is depicted in Figure 1 on the top of the next page. This simulation allows you to vary all of the relevant parameters in the projectile scenario, launch the projectile and find its position as a function of time.

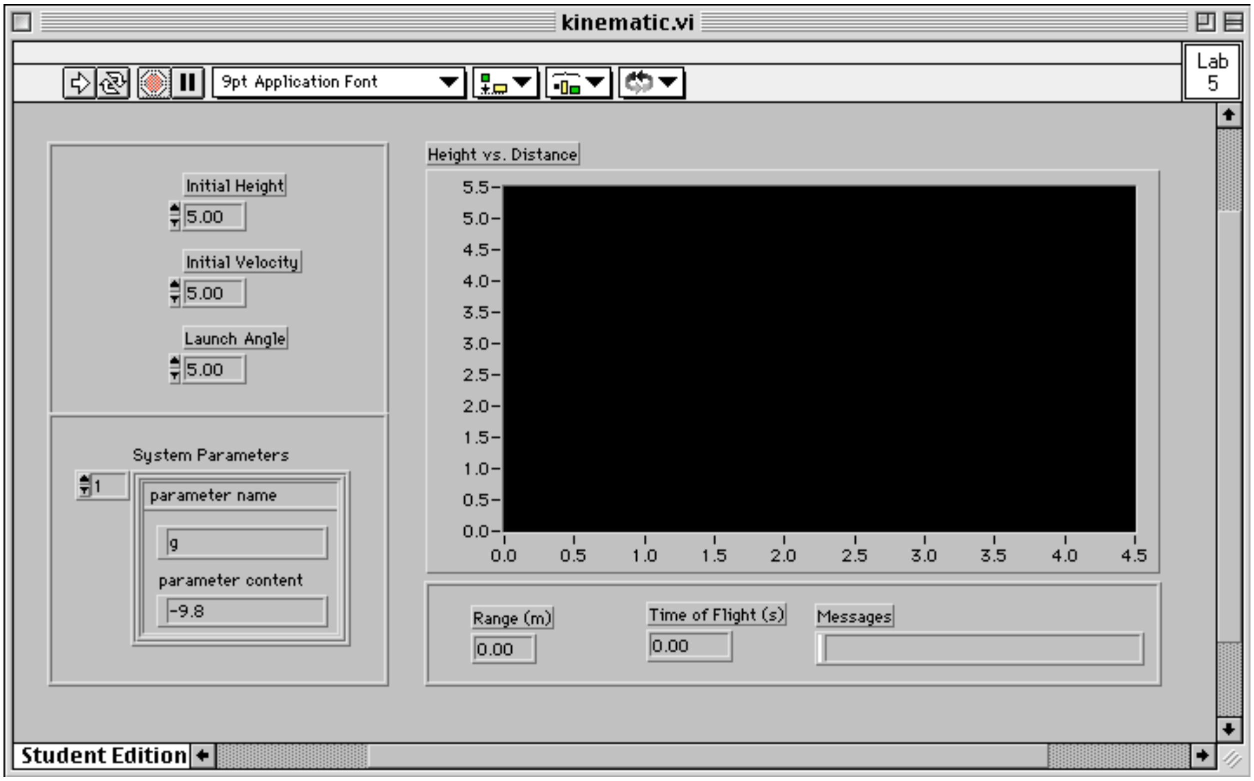


Figure 1

### *3.1 Part I: Horizontal Projection* ***<u>from a 100m-High Cliff</u>***

In this part of the lab, you will examine the motion of an object launched horizontally from a 100 m high cliff. To do this:

- Set the "*Initial Height*" parameter to 100 and the "*Launch Angle*" parameter to 0. (Always hit "enter," each time you change any of the parameter values.)

- Additionally, you will want to make sure that the other system parameters are realistic. In the lower left hand corner, you will see a box labeled "*System Parameters*." By advancing the scroll button, you will be able to change various system parameters that you are investigating.
  - *Option 0* is the mass, *m*, of the projectile (in kg),
  - *option 2* is the acceleration due to gravity, *g* (in $m/s^2$) and
  - *option 3* is the coefficient of viscosity, *b*.

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| The coefficient of viscosity is a property of the size and shape of the projectile, as well as the medium through which the projectile moves. It is analogous to the coefficient of friction that you have seen in class. |

- Set the "*Coefficient of Viscosity"* parameter to be 0 initially and the "*Acceleration of Gravity*" parameter to be –9.8.

- Once the "*Initial Velocity*" parameter is set to the desired value, press the arrow in the bar at the top of the simulation window to run the simulation. When the simulation is complete, the plot will show the trajectory of the projectile and the range and time of flight will be reported in the box below the graph.

- Vary the launch speed parameter, ***v***, from 5 m/s to 70 or 80 m/s and find

  - the time it takes the projectile to hit the ground and
  - the horizontal distance from the base of the cliff $x_o(v)$.

- Record the results in the appropriate columns a data table. (You may, if you wish, just copy and paste your results from each of your runs of the simulation program directly into a table in KaleidaGraph.)

| Next repeat the experiment, including air friction. |
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- Set the "*Coefficient of Viscosity*" parameter to a reasonable value. For a baseball sized object in air, b = 0.02.
- Be sure to record the coefficient of air friction that was used.

| | | Without Air | | With Air | | Range |
|---|---|---|---|---|---|---|
| Launch θ ( ) | Speed v ( ) | Time to ground ( ) | Range $R_o(v)$ ( ) | Time to ground ( ) | Range $R_f(v)$ ( ) | $\frac{R_f(v)}{R_0(v)}$ |
| 0 | 5 | | | | | |
| 0 | 10 | | | | | |
| 0 | 20 | | | | | |
| 0 | 30 | | | | | |
| 0 | 40 | | | | | |
| 0 | 50 | | | | | |
| 0 | 60 | | | | | |
| 0 | 70 | | | | | |

- Plot $\boldsymbol{R_o(v)}$ and $\boldsymbol{R_f(v)}$ vs. ***v***. Attach these plots to the lab write-up. Do you notice any sort of trend in either plot?

- How does the time between launch and impact (“air-time”) vary with the launch speed $\boldsymbol{v}$, when air friction is ignored? Why? What does this have to do with force components?

- How does the “air-time” vary with the launch speed $\boldsymbol{v}$, when air friction is included? Why? (This question deserves extra consideration.)

- Is $\boldsymbol{R_f(v)}$ less than $\boldsymbol{R_o(v)}$? Does this make sense?

- How does the ratio $\boldsymbol{R_f(v)} / \boldsymbol{R_o(v)}$ depend upon the initial speed $\boldsymbol{v}$? Try to explain why this is the case. [Note, pressing the “Apple” key and the “F” key simultaneously brings up the formula entry window in KaleidaGraph. Clicking on a column in your KaleidaGraph data table sets it to “c0” and the column to its immediate right as “c1” and so on. Using this syntax you can generate a new column containing the ratio of your previously entered data for $\boldsymbol{R_f(v)}$ and $\boldsymbol{R_o(v)}$.

### *3.2 Part II: Projection from the Ground at an Angle:*

| Repeat this experiment including air resistance, using the same coefficient as before. |
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- Set up the simulation to launch projectiles from the ground with a fixed launch angle, $\theta = 45°$.
- As before, measure the time of flight and the horizontal range.

- Record your data below.

| | | Without Air Friction | | With Air Friction, b = | | Range Ratio |
|---|---|---|---|---|---|---|
| Launch Angle θ ( ) | Speed v ( ) | Time to hit ground ( ) | Range $R_o(v)$ ( ) | Time to hit ground ( ) | Range $R_f(v)$ ( ) | $\frac{R_f(v)}{R_0(v)}$ |
| 45 | 5 | | | | | |
| 45 | 10 | | | | | |
| 45 | 20 | | | | | |
| 45 | 30 | | | | | |
| 45 | 40 | | | | | |
| 45 | 50 | | | | | |
| 45 | 60 | | | | | |
| 45 | 70 | | | | | |

- Plot $\boldsymbol{R_o(v)}$ and $\boldsymbol{R_f(v)}$ vs. $\boldsymbol{v}$.

- Attach these plots to the lab write-up.

| Do you notice any sort of trend in either plot? |
|---|

- How does the "air-time" vary with the launch speed $\boldsymbol{v}$, when air friction is ignored?

- Is this different from what you found in Part I?

- If so, try to explain the difference.

| Hint: try to fit $\boldsymbol{R_o(v)}$ vs. $\boldsymbol{v}$ using a power law. The value of the exponent here should be close to 2. Why? |
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- How does the "air-time" vary with the launch speed ***v***, when air friction is included? Why? (Again, this question deserves some thought)

- Is $\boldsymbol{R_f(v)}$ less than $\boldsymbol{R_o(v)}$? Does this make sense?

- How does the ratio $\boldsymbol{R_f(v)}$ / $\boldsymbol{R_o(v)}$ depend upon the initial speed ***v***? Try to explain why this is the case.

### *3.3 Part III: Dependence of Range R(θ) on Launch Angle:*

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| To examine the dependence of the range as a function of the launch angle, use the same set-up as in part II and set air-friction to zero. |

- Fix launch speed, ***v**,* to **25 m/s** and systematically vary the angle of launch, $\theta$, to find the angle that maximizes the range. Record any data that you feel is relevant below.

i. What is the optimum angle?

- Now set the launch speed to a bigger number, say, **80 m/s** and again.
- Systematically vary $\theta$ to find the launch angle $\theta$ that maximizes the range.
- Record any data that you feel is relevant below.

i. What is the optimum angle?

ii. Does the optimum angle of launch depend upon the speed?

Theoretically, the range, $R(\theta)$, is related to the launch angle, $\theta$, by Equation (1).

$$R(\theta) = \frac{v_0^2}{g} Sin 2\theta \qquad (1)$$

where $v_o$ is the launch velocity and $g$ is the acceleration due to gravity.

- Are you're results consistent with this expectation? Include any analysis that you feel is appropriate. Be sure to comment on anything that you include.

Repeat this experiment, but include air-friction. Use the same coefficient as you have in previous sections. Record your data below.

i. What is the optimal angle at the lower air velocity?

ii. What is the optimal angle at the larger air velocity?

iii. Does the optimum angle of launch depend upon the launch speed?

iv. Are these results similar to what you found before? Discuss.

### *3.4 Part IV: Dependence of Range on g:*

Simulations allow us to explore physical systems that are not readily available. For instance, you can vary the acceleration of gravity.

- Set the launch velocity, $v_o$, to be **40 m/s** and the launch angle, θ, to be **45°** and vary ***g*** over any range that you like.

| g (   ) | R (   ) |
|---|---|
| | |
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- Attach any graphs or analysis you feel are appropriate.

- Be sure to discuss whatever you include.

❖ From equation (1), how do you expect the range to depend on the acceleration due to gravity? Do the results from the simulation agree with this?

## 4. *Questions:*

Whenever you run a simulation, it is always important to compare its results to the model that has been developed to describe the situation being simulated (*i.e.* to theory).

i. What is the % difference between the theoretical range of a projectile launched with an initial velocity of **300 m/s** at an angle of **45°** and the range found with using this simulation?

ii. Does this simulation accurately model "real life?" What do you think is the source of error?

***5. Initiative:***

## *6. Conclusions:*