~ Lab 5: Slow Down ~

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Research Objectives

1. To predict, observe, & analyze the effects of friction on the movement of an object on an inclined plain, and thereby:
2. To explore how a round-trip on a surface is similar to and different from a round-trip in free fall (i.e. projectile motion), especially as regards the crucial concept of ***symmetry***.

Learning Objectives

1. To observe the analytical power of a free-body-diagram.
2. To scrutinize the subtle but substantial difference that can be made by the direction of a vector (esp., the frictional force vector).
3. To see how the laws of physics can make sense out of simple phenomena -- even if/when they are initially confusing.

Suggested (2-Part) Research Question

1. *If a marble is given some arbitrary initial velocity up a rough plane inclined at some small angle so that it makes a round-trip up and down the plane, continually influenced only by gravity and contact with the surface itself, will the marble's trip up generally take more time, less time or the same time as the trip down?*
2. *WHY? If the forces and accelerations on the marble as it goes up and down the plane are compared using Newton's Laws and the techniques of kinematics, what explanation can be found for the answer to question (1) above?*

A helpful tip for report-writing: your Data Collection section will be mostly about question 1, but 90% of your Analysis section will be about question 2.

Equipment

1. Rough Track.
2. Glider, Cart or Marble: Referred to herein as the "mass"
3. Stopwatch
4. Meter Stick

<u>What is Known</u>

1. GPR
2. Kinematics
3. Newton's Laws
4. That surfaces seem to exert not only a force ***perpendicular*** to their plane, which we call "Normal," but also, when the surfaces are sliding across each other, some sort of force ***parallel*** to that plane and opposite the direction of motion, which we call "Friction."

<u>What is NOT Known</u>

1. Everything else.

<u>Part 1: Prediction</u>

In this experiment, you will give an object an initial velocity so that it slides (or rolls) up an inclined track. Naturally, it will eventually reach a peak height on that slide, stop temporarily and then come back down. You will only touch this object for an instant—right at the beginning. From then on, the object will make its round trip journey under the influences of nothing more than Planet Earth and the track surface. Both of those influences (Earth's gravity and contact with the track) will be relevant throughout the motion studied in this experiment. No other influences should have a significant impact on the object's motion.

Discuss with your group what you qualitatively expect to happen. As a group, you must then agree on and write down a ***PREDICTION*** regarding the following question:

*Will the object's trip **UP** the slide take:*

a) *measurably **MORE** time than the trip back down,*
b) *measurably **LESS** time than the trip back down or*
c) *essentially the **SAME** amount of time as the trip down?*

(What do we mean by "measurably" or "essentially"? These are qualifiers that are best addressed/understood through uncertainty analysis!)

After you make a prediction, proceed through the experiment. Note that, both in your research and in your formal report, you may treat your prediction as an ***active hypothesis***, as in "we believed *x* and we performed an experiment to see if we were right" or ignore it and pursue an ***open ended research question***, as in "We wanted to see if *x*, *y*, or *z* was the case"

Part 2: Experimental Investigation

1. Make sure your track is inclined at an extremely shallow angle. This is very important: you must have a VERY slight angle, in order to be able to obtain good data.
   a) Create an angle by elevating one end of the track.
   b) Place your mass at the bottom end of the track and give it a SMALL initial velocity up the track by flicking or otherwise thrusting it with your finger.
   c) Try out different elevations.
   d) Your goal is to ***find the smallest possible elevation (i.e. the shallowest possible angle) such that when you send the mass UP the track with a very SMALL initial velocity, it will eventually TURN AROUND and ROLL BACK DOWN THE TRACK.***
   e) Once you have found the minimum possible angle at which the mass will still roll back down, use your meter stick and your knowledge of trigonometry, calculate the angle of inclination between the track and the horizontal lab table. Call this angle "theta".

      It will not at first be obvious what measurements you should use for this calculation. To figure it out, you will need to make a ***careful***, ***accurate*** drawing of your tilted track. There are a few different right triangles that the track forms with the table. You need one whose legs are easy to measure and whose hypotenuse is ***parallel to the surface of the track***.

   f) Theta = __________________ degrees.

2. Practice sending your mass on a long round-trip starting at the bottom of the track:
   a) Your goal is to flick the mass so as to send it as high up the track as possible--but without passing the top edge and falling off.
   b) Once the mass reaches a peak height, it should slide back down -- all the way to its original position. If it does not, incrementally increase the angle of your track just until the mass can complete a round trip with no help—other than the initial flick.
   c) Your initial velocity ('flick') will never be precisely reproducible and that, as you will ultimately see, is ***not*** a problem in this lab.
   d) Rather than a precisely reproducible initial velocity, you want to assure yourself that you can manage a generally reliable initial velocity—one that sends the mass most of the way up the track. Once you are confident of this, proceed to the next step.

3. Define a coordinate system for your track. Although this might seem premature, defining the coordinate system now will help you keep your work consistent mathematically.

   Notice that the marble's trip is one-dimensional. Therefore your coordinate system should need only one axis. This one axis does ***not*** need to be horizontal or vertical. It does need to align with the ball's motion, so that all the motion is on this one axis. Don't forget to define -/+ directions. ***Keep these directions in mind as you record data in the trials below.***

4. Send your mass on AT LEAST five (5) separate round-trip TRIALS. For EACH TRIAL, you must independently measure the following:
   a) One-Way Displacement,
   b) Up-Trip Time,
   c) Down-Trip Time.

   Note: Due to the non-reproducible "flick", each trial may have a different displacement—and two different times. Measuring all these quantities in "real time" can pose a challenge. It is nonetheless quite possible and simply requires that you thoughtfully delegate different tasks to different lab group members. Do not, for example, try to literally measure displacement while the mass is in motion. Simply use a finger or pencil to mark how high the mass gets and measure *d* after the mass comes to rest. Etc.

5. Present the data from your trials in a table of this form:

Trial [#]	**Up-Trip Displacement [m]**	**Down-Trip Displacement [m]**	**Up-Trip Time [s]**	**Down-Trip Time [s]**
1				
2				
3				
4				
...				
Average (mean)				

6. Once you have computed an average for each of the three columns in table, D1, above, do whatever calculations are necessary to complete a table of the following form:

	Up-Trip Average Velocity [m/s]	**Down-Trip Average Velocity [m/s]**	**Up-Trip Final Velocity [m/s]**	**Up-Trip Initial Velocity [m/s]**	**Down-Trip Initial Velocity [m/s]**	**Down-Trip final velocity [m/s]**	**Up-Trip Average Acceleration [m/s^2]**	**Down-Trip Average Acceleration [m/s^2]**
Average of Trials								

7. In three to five complete sentences of English, answer the following question.

   Do any of the data surprise you in any way?

   If so, specifically explain how they differ from what you predicted. If not, specifically explain how they are consistent with what you predicted. Once you are writing this up fully and formally, make sure that any comparisons you are making are related back to the range of possible values produced by your UNCERTAINTIES.

<u>Part 3: Theoretical Investigation</u>

You are now at an important moment in any scientific investigation: you have discovered something surprising. Specifically, you have discovered that, although a round trip on an inclined plane ***looks*** a lot like a round trip in free-fall, they are different in an important, substantive way.

1. Try to write down, in one simple, concise sentence, what the difference is. (Hint: your answer may involve the concept of ***symmetry***.)

So, we have discovered something surprising about the world. Since we are scientists, what do we do now? Of course, we ask: ***why?*** Why does this surprising thing happen?

For an answer, we look to our scientific theories. Can our theories explain our data? If they can, then this gives us new reasons to believe in them. If, they cannot, then we need a new theory!

The final section of this lab is about using our theoretical framework (Newton's laws) to try to explain what you discovered in the previous section of the lab.

2. Draw a "pure" Free-Body-Diagram (FBD) of the mass for one instant during its UP-TRIP. This instant should be significantly AFTER the source of initial velocity ("flick" finger) has been released from the mass. "Pure" means that each force should be depicted as a vector that points fully in the direction you observe the force acting in the lab. That is, just depict the simple and straightforward direction: Do NOT divide vectors into components.

3. Draw a "pure" FBD of the mass for one instant during its DOWN-TRIP. This instant should be significantly BEFORE the mass reaches the bottom end of its journey.

4. You will notice that your diagrams include forces pointing in directions that are not all parallel nor perpendicular. You will need to add an ***x-y coordinate-system***. But this coordinate system will ***NOT*** be horizontal-perpendicular like a normal coordinate system. Instead it will be rotated, so that the X-axis lines up with the direction of the ball's acceleration (down the ramp) and the Y-axis (as always) is perpendicular to the X-axis.

Given this new coordinate system:

5. Break up the force of ***mg*** into two components: one that lies along this ***slanted*** x-axis and one that lies along the ***slanted*** y-axis. One component will be "***mg sin theta***" and one component will be "***mg cos theta***". Think quite carefully about which one is which.

6. Using your new gravity COMPONENTS (instead of mg itself), Draw a "component" FBD for the UP-TRIP.

7. Using your new gravity COMPONENTS (instead of mg itself), Draw a "component" FBD for the DOWN-TRIP.

8. EACH member of your group should draw his/her OWN component FBD for each trip. Your lab instructor ***may*** choose to collect these individual FBDs.

9. Using the component FBD for the UP Trip, write down and "expand" Newton's 2nd Law for EACH axis of the Up Trip .

- The LEFT side of Newton's 2nd Law requires that ALL FORCES along a particular axis be summed up. Your FBD is telling you what forces to sum up.
- Numbers are not yet expected; only ***variables*** to represent the various forces.

10. Using the component FBD for the DOWN Trip, write down and "expand" Newton's 2nd Law for EACH axis of the Down Trip .

AND NOW… the (two-part) PUNCHLINE:

11. In one to three sentences of English, use your expanded applications of Newton's 2nd Law to explain why the magnitude of the average acceleration UP should be larger than the magnitude of the average acceleration DOWN.

12. In one to three sentences of English, use your knowledge of kinematics to explain why the LARGER (magnitude) average ACCELERATION up leads to a SMALLER average TIME up—and vice versa.

13. One more step: you already have the answers to your RQs, but for the sake of thoroughness, we'd like to find the ***coefficient of friction***.

In fact, in this situation, what we are dealing with is not standard ***sliding friction*** but ***rolling resistance*** (denoted $\boldsymbol{f}_{\mathbf{r}}$) Nonetheless, it is still ***approximately proportional to the relevant normal force***, so we can still try to find the ***constant of proportionality***.

As you know, for sliding friction, that constant of proportionality is written as **μ** ("mu"). For rolling friction it's written as C_{rr} ("Coefficient of Rolling Resistance"), and the equation that defines it looks just like the one for **μ**:

$$C_{rr} = \frac{f_r}{N} \qquad or \qquad f_r = C_{rr}N$$

Use a scale to weigh your marble. Compute ***mg*** and its components, and substitute in to your Newton's Second Law equations from step 10.

Ask yourself: what is the y-component of acceleration? What is the x-component? (**HINT:** they're ***not*** the same, but you already know both of them!)

Solve your Newton's Second Law equations to find the magnitudes of **N** and $\boldsymbol{f}_{\mathbf{r}}$.
Solve for $\boldsymbol{C_{rr}}$.
You will get two values: one from the up-trip and one from the down-trip. Theoretically, if your data were perfect, these two values would be the same. Feel free to average them.