Name: ____________________________________ **Period:** _____ **Due Date:** ___________
Lab Partners: ____

NEWTON'S SECOND LAW - WebAssign

Purpose: To examine the application of Newton's Second Law **($\Sigma F_{EXT} = ma$)** to two-body tension problems involving masses in frictionless, linear motion

Basic Procedure:

1. Level the air track! Don't lean on the tables. Do not slide the air track after leveling it.

2. Tie a string to a rubber band bumper on the front of the glider and to a 50-gram hanger. Pass the string over a smart pulley at the end of the air track to enable the hanger to pull the glider along the rail. Place a photogate so that it looks through the spokes of the smart pulley.

3. Start LoggerPro and open the file named "Newton's Second Law." This file is set-up to report the **Velocity vs. time** data from one run down the track. Both numbers and a graph are presented.

4. A graph of the velocity vs time data points will appear in the graph-window.

5. Select **Set-up : Data Collection : Sampling : User Defined.** In the text box enter the appropriate calibration-constant for the pulley you are using.

   Enter **0.01509** if you are using the **10-spoke** pulley wheel.

   Enter **0.01778** if you are using the **8-spoke** pulley wheel.

   (*The calibration constant is the distance along the circumference of the pulley from one spoke to the next. LoggerPro uses this distance and the recorded times to calculate the instantaneous velocity.*)

6. Hold the glider in the ready position with the air on, and then click the COLLECT button. Hold the glider with the hanger hanging just below the pulley. Two or three seconds after clicking the COLLECT button, release the glider so the hanging weight can pull it along the rail. Turn off data collection mode after the glider completes its run down the track. ***(Do not allow the glider to crash into the end of the rail.)***

7. **Highlight the linear portion** of the graph for analysis. Select **Analyze : Linear Fit.** The best linear fit to the highlighted section of the graph will appear. The slope (***M***) of the line is equal to the acceleration of the glider ***(remember the equation:*** $v = v_o + at$***;*** *in this case* v_o *may or may not equal zero.* ***All we care about is the slope, which is to say, the acceleration).*** Your instructor will show you how to use the Graph window to obtain your first linear fit.

8. The resulting graph should be a very good straight line. If it is not, then repeat the experiment. Record the slope (***M***). The slope is the acceleration of the glider, hanger, and string.

9. Part I & Data Table I: Changing the Mass of the Glider

Repeat the basic procedure for these three trials.

Use the 50-gram hanger with **NO** added weights in all three trials.

Trial #1 - Use the glider with **NO** added weights,

Trial #2 - Use the glider with 100 grams added (2 disk weights), and

Trial #3 - Use the glider with 200 grams added (four disk weights).

DATA TABLE I

Mass of hanger = ___________ kg

Mass of glider = ___________ kg

Mass of 2 disk weights = ___________ kg

Mass of 4 disk weights = ___________ kg

See Analysis Section for instructions.

Trial #	**Mass of Glider & Weights** *(kg)*	**Measured Acceleration of Glider & Weights** *(m/sec^2)*	**Predicted Acceleration of Glider & Weights** *(m/sec^2)*	**%Error**	**Tension in String** *(N)* *(from measured acceleration)*
1	__________	___________	__________	__________	__________
2	__________	___________	__________	__________	__________
3	__________	___________	__________	__________	__________

Do not attempt the calculations in the right-hand box during the lab. The analysis section will explain what to do and how to do it. While you are in the lab, spend your time gathering the data. The calculations can be done outside of the lab, the measurements cannot.

You must return in the next day or two to repeat any run for which the %Error exceeds 10%. Don't delay doing the calculations because the apparatus is going to disappear into storage very soon.

10. Part II & Data Table II: Increasing Hanger Weight

Repeat the same basic procedure for these five trials.

Keep the glider fully loaded with all 4 disk weights in all five trials.

Varying the mass on the hanger by adding 10 grams to each successive trial.

Trial #1: Use the hanger with 10 grams added; Mass of Hanger & Weights = 60 grams,

Trial #2: Use the hanger with 20 grams added; Mass of Hanger & Weights = 70 grams,

Trial #3: Use the hanger with 30 grams added; Mass of Hanger & Weights = 80 grams,

Trial #4: Use the hanger with 40 grams added; Mass of Hanger & Weights = 90 grams,

Trial #5: Use the hanger with 50 grams added; Mass of Hanger & Weights = 100 grams.

You don't need to run the hanger without added weights because you've already run the fully loaded glider with the 50-gram hanger in Trial #3 of Part I).

DATA TABLE II

Mass of glider + 4 disk weights = ___________ kg

			See Analysis Section for instructions.		
Trial #	**Mass of Hanger & Weights** *(kg)*	**Measured Acceleration of Glider** *(m/sec^2)*	**Predicted Acceleration of Glider** *(m/sec^2)*	**%Error**	**Tension in String** *(N)* *(from measured acceleration)*
1	__________	___________	__________	__________	__________
2	__________	___________	__________	__________	__________
3	__________	___________	__________	__________	__________
4	__________	___________	__________	__________	__________
5	__________	___________	__________	__________	__________

Do not attempt the calculations in the right-hand box during the lab. The analysis section will explain what to do and how to do it. While you are in the lab, spend your time gathering the data. The calculations can be done outside of the lab, the measurements cannot.

You must return in the next day or two to repeat any run for which the %Error exceeds 10%. Don't delay doing the calculations because the apparatus is going to disappear into storage very soon.

11. Part III & Data Table III: Changing Angle of Inclination

Take the all weights off both the glider and the hanger.

Repeat the same basic procedure for these five trials.

Before you begin, estimate the height of one book, by measuring the height of 10 identical books in a stack. (*These are the thin paperback books available in the lab cabinet.*) Press down hard on the stack of ten before you measure its thickness. This squeezes out the air and flattens the pages.

Divide by 10 to get the average thickness of one book.

Elevate the pulley-end of the track using books from your stack. Vary the number of books in the stack with each trial.

Trial #1: Use 2 books to elevate the rail. The glider and the hanger have **NO** added weights,

Trial #2: Use 4 books to elevate the rail. The glider and the hanger have **NO** added weights,

Trial #3: Use 6 books to elevate the rail. The glider and the hanger have **NO** added weights,

Trial #4: Use 8 books to elevate the rail. The glider and the hanger have **NO** added weights,

Trial #5: Use 10 books to elevate the rail. The glider and the hanger have **NO** added weights,

DATA TABLE III

Mass of empty glider = ___________ kg Thickness of ten books = ___________ m

Mass of empty hanger = ___________ kg Thickness of one book = ___________ m

See Analysis Section for instructions.

Trial # *(# of Books)*	**Height of Books** *(m)*	**Measured Acceleration of Glider** *(m/sec^2)*	**Predicted Acceleration of Glider** *(m/sec^2)*	**%Error**	**Tension in String** *(N)* *(from measured acceleration)*
1. (2)					
2 (4)					
3. (6)					
4. (8)					
5. (10)					

Do not attempt the calculations in the right-hand box during the lab. The analysis section will explain what to do and how to do it. While you are in the lab, spend your time gathering the data. The calculations can be done outside of the lab, the measurements cannot.

You must return in the next day or two to repeat any run for which the %Error exceeds 10%. Don't delay doing the calculations because the apparatus is going to disappear into storage very soon.

Analysis:

[You must show <u>Sample Calculations</u> on page 7; clearly show the algebraic method and the numerical outcome for each calculation used to analyze **Trial #1** in each of the three data tables.]

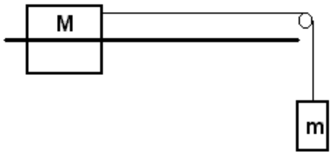
Parts I and II

Predict the acceleration of the glider using ***Equation 1.***

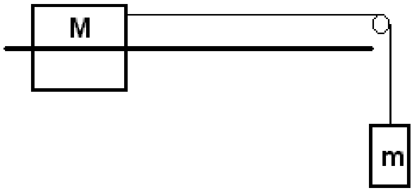
Calculate the tension in the string using the <u>measured acceleration</u> and ***Equation II***.

Enter the predicted accelerations and the calculated tensions in Data Table I & Data Table II.

Calculate, as percent error, the difference between measured and predicted accelerations. Assume the predicted acceleration is correct. Enter the percent error between measured and predicted accelerations in Tables I & II.

Equation I M is the mass of the glider. m is the mass of the hanger. *(use g = +9.81 m/s^2, since I've assumed that right and down are the positive directions in deriving these expressions.)*	$m\mathbf{g} = (M + m)\, a_{predicted}$	 Figure Lab 12-01
Equation II $\|T_{calc}\|$ is the magnitude of the tension in the string. On our force diagram. T points in both negative and positive directions.	$\|T_{calc}\| = m(\mathbf{g} - a_{measured})$ The acceleration is positive (+).	

On the diagram below **draw the force diagram** showing all the forces acting on each mass. Do not include the weight of the string or the pulley. The diagram should **show five force vectors** when completed.



Part III

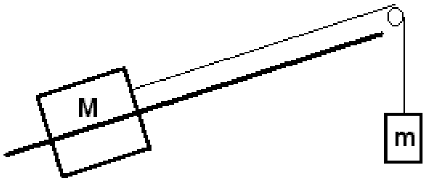
The sine of the inclination angle equals the “Height of Books” in meters divided by the distance between the legs of the air track (which happens to equal 1.0000 meter). (Recall that sin θ = opp/hyp.)

Predict the acceleration of the glider using ***Equation III***.

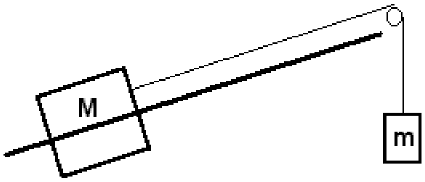
Calculate the tension in the string using the <u>measured acceleration</u> and ***Equation IV***.

Enter the predicted accelerations and the calculated tensions in Data Table III.

Calculate, as percent error, the difference between measured and predicted accelerations. Assume the predicted acceleration is correct. Enter the percent error between measured and predicted accelerations in Tables III.

Equation III *(use $g = +9.81\ m/s^2$, since I’ve assumed that up the slope and downward are the positive directions in deriving these expressions.)* ***Equation IV*** $|T_{calc}|$ is the magnitude of the tension in the string. On our force diagram. T points in both negative and positive directions.	$m\mathbf{g} - M\mathbf{g}\sin\theta = (M + m)\ a_{predicted}$ $|T_{calc}| = m\ (\mathbf{g} - a_{measured})$ The acceleration is positive (+).	 Figure Lab 12-02

On the diagram below **draw the force diagram** showing all the forces acting on each mass. Show the two components of the weight of mass M. Do not include the weight of the string or the pulley. The diagram should **show five force vectors, plus the two relevant components of Mg**, when completed.



Sample Calculations: See top of page 5 for instructions. Show all the calculations for the first trial in each data set. These should be neat and well organized.

Answer these Experimental Questions: (Answer #1 - #6 after you finish the sample calculations.)

1a. Rearrange ***Equation I*** and solve for **g**. Now, use the measured acceleration, **NOT** the predicted acceleration, the known masses and your equation for **g** to estimate the local value of **g** from the data in each trial in **Parts I & II**.

g = ______________________________________

Estimate of **g** --- from Trial #1 in Table I) = ____________________________ m/s^2

Estimate of **g** --- from Trial #2 in Table I) = ____________________________ m/s^2

Estimate of **g** --- from Trial #3 in Table I) = ____________________________ m/s^2

Estimate of **g** --- from Trial #1 in Table II) = ___________________________ m/s^2

Estimate of **g** --- from Trial #2 in Table II) = ___________________________ m/s^2

Estimate of **g** --- from Trial #3 in Table II) = ___________________________ m/s^2

Estimate of **g** --- from Trial #4 in Table II) = ___________________________ m/s^2

Estimate of **g** --- from Trial #5 in Table II) = ___________________________ m/s^2

1b. Rearrange ***Equation III*** and solve for **g**. Now, use the measured acceleration, **NOT** of the predicted acceleration, the known masses and your equation for **g** to estimate the local value of **g** from the data in each trial in **Parts III**.

g = ______________________________________

Estimate of **g** --- from Trial #1 in Table III) = ____________________________ m/s^2

Estimate of **g** --- from Trial #2 in Table III) = ____________________________ m/s^2

Estimate of **g** --- from Trial #3 in Table III) = ____________________________ m/s^2

Estimate of **g** --- from Trial #4 in Table III) = ____________________________ m/s^2

Estimate of **g** --- from Trial #5 in Table III) = ____________________________ m/s^2

1c. Suppose, in Part I, that you made the glider lighter and lighter. What is the maximum possible value of the acceleration? In other words, what is the maximum theoretical acceleration <u>in the limit</u> as the mass of the glider approaches zero? (*The mass of the hanger is always greater than zero*.)

a (MAX) = ___ = ___________ m/s^2

1d. Suppose you could tilt the rail to any angle between –90º and +90º, where 0º is horizontal. At what angle(s) will $|a| = |\mathbf{g}|$? (*Let +90º indicate that the pulley is high, and –90º indicate that the pulley is low*.)

2. If we did all these experiments again on Mars, what <u>specific</u> differences would you expect to observe? ($|\mathbf{g}_{\text{Mars}}| = 3.8\ m/s^2$.)

3. If m = 2.0 kg and M = 9.0 kg, what elevation angle θ will give you an acceleration of zero?

$\theta_{\mathbf{balance}}$ = ________º (3SF)

4. If you switch the masses in question #3, can you get an acceleration of zero by tilting the track? Circle one answer and explain why or why not.

YES or **NO** ____

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____

5. If m = 2.0 kg and M = 9.0 kg, and if the track is level, what minimum value of the coefficient of static friction will ensure that the glider does not move; i.e. that the acceleration will be zero?

μ_S = __________ (3SF)

6. The true local value of **g** at this school is ___________ m/s^2.

Find the <u>average value of your estimates</u> of **g** made in questions 1a. and 1b. above.

Average value of **g** = __________________________ m/s^2

Calculate the percent error between the true local value of g and your average estimate of **g**.

%Error (in estimates of **g**) = __________________________

Two Hypothetical Problems – Think first.

First Hypothetical Problem

In this lab we elevated the rail at the end with the pulley. Suppose we could elevate either end of the rail.

Create a graph (call it **Graph 1**) showing how you expect the measured acceleration to vary as a function of elevation angle across a range of angles from –90º to +90º, where horizontal means a tilt of 0º. This graph of ***Acceleration vs Inclination Angle*** must show the calculated acceleration every 10º from –90º and +90º, inclusive. Assume that the glider and hanger both have masses of 0.400 kg. Thus, M = m = 0.400 kg.

(*The calculated acceleration must be zero when the angle is +90º and the acceleration must be –9.81 m/s*^{2} *when the angle is –90º. This result ASSUMES that when the angle is positive, the pulley end is high and that when the angle is negative, the pulley end is low. Make sure your graph is consistent with this assumption.*)

Second Hypothetical Question

Aristotle (384 - 322 BCE) said that heavier objects fall faster than lighter objects. This erroneous conclusion was taken as fact for almost 2000 years until Galileo (1564 - 1642 CE) finally decided to try an experiment. Newton (1643-1727) and the rest of us owe a debt of gratitude to Galileo for providing this insight and for pointing out the primacy of experimental evidence over mere logic and imagination, however well informed. Aristotle thought he was using logic alone, but all he did was convince himself that his original assumption was correct. Today we expect substantive data to provide the foundation of any conclusions drawn about the behavior of natural and man-made systems. Indeed, scientists gather data daily about how the universe itself works. There appears to be no physical system beyond the reach of the scientific method, which relies on measurable, rather than merely logical, evidence.

Try to imagine what the world would be like if Aristotle had been correct.

$$\boxed{\mathcal{V} = \mathbf{w}\,\mathcal{M}}$$

In the world of imagination, what Aristotle meant to say (in modern terms) about freely falling bodies may have been something like that shown in the box. We imagine that the Earth "creates" the “Motivation”, $\mathcal{M}$, let’s call it, which acts on the weight, **w**, to force a body to move with constant velocity $\mathcal{V}$. Aristotle did understand that the velocity could change during what he called unnatural motion, such as a cart being pushed. Objects seeking their natural position, such as a falling object, moved at their natural speed. He assumed dropped objects went from zero to their final velocity, instantaneously. Aristotle further claimed that heavier objects have a larger natural velocity than lighter objects. The kindest way to put this is to say that Aristotle made a guess and was wrong. The less kind view of Aristotle, is to say that he was too arrogant to take the time to examine the situation as closely as it deserves. In any event his comments are vague and non-quantitative.

He did not ask enough questions: How did he miss the obvious acceleration of falling objects? What if the motivation is not a constant? He did consider air resistance, but he got that wrong, too. Examining these and other questions would have led him, eventually, to a position where he had to try an experiment. There are no obvious answers to be found by merely thinking about what “should” happen. Logic alone is not powerful enough to understand the universe. It’s amazing that his immense curiosity did not eventually drive him outside to watch a few rocks fall.

If Aristotle had discovered the value of doing experiments 2000 years before Galileo, we would live in a very different world today. With two additional millennia of technology under our belts, there is no telling what our world would be like or where in the universe we might be exploring today.

Assume for the purposes of this mini-section that Aristotle was right; that the Earth produces a constant “Motivation” that compels each object to move with a fixed velocity according to its weight. Note that there is no quantity in physics today comparable to $\mathcal{M}$. Note, too, that there is no quantity in physics today comparable to $\mathcal{V}$, the fixed universal velocity of a falling object. (*Our velocities change with time and our accelerations change with distance from the center of the Earth or the nearest large body.*)

What are the units of “Motivation” in this hypothetical situation (*assuming velocity is still measured in m/s and weight is still measured in something we can call a newton, N*)?

Aristotle’s units of Motivation (in units of m, s, and N) = ____________________

If we consider dropped objects only, today, we expect the velocity at time t to be v = at = gt. The units of velocity are m/s. Recall that g has units of m/s^2 or N/kg. Therefore, we can also express velocity in units of N·s/kg. This is a problem for Aristotle since he only discusses weight and never discusses the different and more fundamental quantity called mass. It is part and parcel with his overall ignorance about how the real world works that he did not entertain the possibility of such a quantity as mass, distinct from weight.

Explain the difference between mass and weight. ____

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Aristotle believed, perhaps it was an article of faith, that the universe was capable of rational understanding. That much seems to be universally accepted even today. His mistake was believing the universe could be understood using rational thought alone. We now understand, thanks in part to Galileo's early efforts, that the rational thought experiment can be supported or refuted only through carefully controlled experiments, thorough observations, and logical interpretations of the data.

Galileo loved to impress his wealthy patrons, and score points for the new science, by conducting demonstrations in the form of experiments. One of his larger ones involved letting a brass ball roll down a long incline. He was interested in studying the acceleration of the ball as it rolled down the slope. Does this sound at all familiar? When he actually did this experiment for himself he used a water clock to measure the times, but in his demonstrations he used bells to sound the times.

Suppose that you have a 10-meter board and a metal ball to roll down it. Image three bells arranged so that the ball brushes up against each of them in turn as it passes, but is not slowed in its acceleration. Place the first bell at the top, the second 1/4th of the way down, and the third bell at the bottom. This produces two time differences: $t_{1\text{-}2}$, and $t_{2\text{-}3.}$

Because the distance traveled increases as the time squared, when acceleration is constant, we and Galileo expect that the time used to move 1/4th of the way down the hill will be half the time it takes to move all the way to the bottom of the slope. In other words, if you double the time you quadruple the distance covered.

$$2\cdot t_{1\text{-}2} = t_{1\text{-}2} + t_{2\text{-}3} \qquad \text{therefore} \qquad t_{1\text{-}2} = t_{2\text{-}3}$$

Now, suppose that we, or Galileo, place 11 evenly spaced bells along the track, with the first at the top and the eleventh at the bottom. Describe how the timing of the bells changes as the ball rolls down the slope. (*The ball rolls silently except when it brushes against the bells.*)

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If Aristotle had tried, or even tried to imagine, as you have, an experiment like this, he would have been immediately confronted with the evident fact that velocities are not constant even for objects moving in their natural direction. For velocity to be constant, the bells would have to ring at equal time intervals, but they don't.

Galileo performed this experiment as a demonstration just to as simply and emphatically as he could that Aristotle got it wrong. Galileo's rejection of Aristotle's non-experimental method, and his advocacy of experiments as the ultimate judge of the worth of a theory, lead to the beginnings of the Scientific Revolution, which lead to the Industrial Revolution, which lead to our current technological revolution.

How did Aristotle, by all accounts a very bright guy, get it so wrong? To answer that question, write a short sentence or two about what Aristotle should have attempted, but never did.

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