Name: ______________________________________

LAB 5. BALANCED AND UNBALANCED WEIGHT

Introduction

This lab comprises two activities. In one, you balance a cart free to roll on a ramp against a hanging mass; in the other, you measure the acceleration of a cart pulled by a hanging weight.

Supplies

Both activities: dynamics cart with a string, mass hanger and masses
Balance: adjustable ramp with pulley, level, protractor or meter stick and plumb line
Rail cart: track with pulley, auxiliary cart, motion detector apparatus, level, pad for the floor

Data Collection

Balance

A string running over the pulley at the end of the ramp connects a mass hanger to a dynamics cart. For a given hanging mass (less than the cart mass), find the inclination angle of the ramp that keeps the cart and hanging weight from accelerating either up or down.

1. Measure and record the mass M of the cart. M = ________________________.
2. Level the ramp.
3. Place the needed mass m (20 g, 50 g, 70 g, 100 g, 150 g, and 200 g if you are using a metal cart; 20 g, 30 g, 50 g, 70 g, and 100 g if a plastic cart) on the hanger. Run the string over the pulley at the end of the ramp.
4. Adjust the ramp incline angle so that the cart rolls neither up nor down. Check the angle by pushing the cart up the ramp and down the ramp. It should coast to a stop in about the same distance and time in both directions. Secure the ramp in place.
5. Record the angle α. If you don't have a protractor, measure the altitude y above the ground and the hypotenuse r along the ramp to a point on the ramp. Then $y/r = \sin(\alpha)$.
6. Complete steps 3–5 for each hanging mass.
7. Repeat the measurements (steps 3–6) for all hanging masses three times, by three different experimenters.

	Angle α (degrees) or y, r (cm or m)		
Hanging mass m (g)	Experimenter 1	Experimenter 2	Experimenter 3

Rail cart acceleration

This time, the track will be level and you will allow the hanging weight to fall and pull the cart. You will explore different combinations of hanging weight *m* and cart mass *M*. You will use the motion sensor to find its acceleration.

Set up

1. Use the balance to find the masses of the dynamics cart and auxiliary. It's probably a good idea to also measure the mass of the hanging weights as a reality check on their markings or the balance.
2. Level the track on the table. Mount a pulley at the end of the track at the edge of the table. Position a motion detector at the opposite end of the track.
3. Assemble the cart apparatus.
4. Connect the motion sensor and check its settings.

Hanging mass

1. Connect the string to the cart.
2. Place the pad under the hanging weight so that it does not crash to the floor.
3. Begin with a fairly small hanging mass on the string, perhaps 20 g.
4. Hold the cart still. Begin data collection. Let the cart go to be pulled along the track by the falling weight.
5. Catch the cart before it hits the pulley at the end of the track. Stop data collection.
6. Make a velocity-time plot. Find the region of the plot when the velocity increases linearly. Fit this region with a linear fit. Record the slope of this fit: this is the acceleration during this time. (If you prefer, you can make an acceleration-time plot and find its average over a suitable interval. Why do I recommend finding the slope of a velocity-time plot?)
7. Repeat steps 4-9 for increasingly massive hanging weights. If time permits, try it with an auxiliary mass on the cart as well. Oh, it's also a good idea to repeat measurements with the same *M* and *m* to check if the accelerations are the same.

M (g)	m (g)	a (m/s^2)	M (g)	m (g)	a (m/s^2)

Data Processing

Using a spreadsheet will make this easiest. Truly.

Balance

1. Average the angle readings for each hanging mass.
2. Calculate $M \sin(\alpha)$, where α is the angle and M is the mass of the cart, for angles $\alpha = 0°$, 1°, 2°, 3°, … 45°.
3. Make a scatter plot of observed hanging mass m (vertical axis) vs. measured angle α (horizontal axis). On the same axes, plot the smooth curve of $M \sin(\alpha)$ vs α.

Rail cart

1. Find the formula for the expected acceleration of an ideal frictionless cart of mass M pulled by a hanging mass m. Record it here. (You'll explain it in the Theory section of your report.)

2. Find the formula for the expected dynamic tension in the string when the cart is being accelerated by the falling weight. Record it here. (You'll explain it in your report.)

3. Make a spreadsheet column to calculate what the acceleration a_{calc} of the cart should theoretically be for each experiment.
4. In another column, calculate the "residuals" s_a of the accelerations, that is, the differences between the measured and predicted values, $s_i = a_{i\,\text{calc}} - a_i$.
5. Make scatter plots of:
   - a_i and $a_{i\,\text{calc}}$ vs. hanging mass m (both a series together in the same graph)
   - the acceleration residuals sa vs. hanging mass m (basically the same information as the previous plot, but with the difference between theory and measurement isolated)

Lab Report

The analysis is the key part of this lab, so please make sure it is complete and correct. Lab reports may be turned in by lab groups (of no more then four students each), but I urge all students to contribute to and fully master the analysis.

Abstract and Purpose

Give a few sentences for each. What did you do, and what aspect of physics was this intended to illuminate?

Theory

Explain the mathematical/physical model (equations predicting the tension in the string and acceleration of the objects) for the static balanced system and for the accelerating cart pulled by a hanging weight.

Experimental

In a few sentences, describe the apparatus, what you did with it, and the measurements you took. Identify commercial products by manufacturer and model.

Observations and Data

Show the raw data tables. You may simply attach or scan these pages with the tables completed, or the data may be transcribed into a submitted spreadsheet (recommended).

Analysis and Discussion

Graphs

Show the graphs that you made: m and $M \sin(\alpha)$ vs. α from the balance activity; and the acceleration plots and residuals plots from the rail cart activity. Make sure that the graphs are clearly labeled as to what they are, and that their axes are clearly labeled and easy to read. These graphs can be part of a submitted spreadsheet.

Questions

Answer the following questions thoroughly.

Balance

Q1. Draw two free body diagrams: one for the cart at rest on the ramp, and the second for the hanging weight. Label all the forces.

Q2. What is the formula for the tension in the string when the cart is at rest? This formula should depend on the hanging mass, the cart, and the incline angle of the ramp. You may assume that the string is massless and inextensible, and that the pulley is frictionless. Show your derivation of the formula.

Q3. Do the hanging mass data coincide with the $M \sin(\alpha)$ curve? Should they? Explain.

Rail cart

Q4. Draw two free body diagrams: one for the accelerating cart, and the second for the falling weight. Label all the forces.

Q5. What is the formula for the acceleration of the cart and falling weight? Show your derivation of the formula, which should depend on masses M and m, and gravitational field g. Assume that the string is massless and inextensible, that the pulley is massless, and that the pulley, track, and cart wheels are frictionless.

Q6. Do the calculated and measured accelerations match? Compared to the measured acceleration, how large are the residuals?

Q7. Is there a pattern to the residuals plot? If there is or isn't, what does that mean?

Conclusions

Do the models adequately represent the physical systems? Identify the evidence supporting your assessment.