EXPERIMENT 4: ATWOOD MACHINE -- NEWTON'S SECOND LAW

In this experiment we use perhaps the most common equation in physics: F = ma. There are various ways of confirming this equation experimentally. One choice is to vary only the mass, keeping F (meaning F_{net} of course) constant, and see how a varies. The second choice is to keep m constant and change F, and see how a varies. We will use these two approaches.

ADVANCED STUDY ASSIGNMENT

1. Mass m_1 and mass m_2 are hung from a light string over a "massless", "frictionless" pulley. Assume $m_1 > m_2$ and derive a formula for the acceleration of the system. You may find useful examples in Chapter 5 of your textbook.
2. Would you expect the actual acceleration of the system to be more or less, if the effect of friction were included in our analysis?

BACKGROUND

There are various ways to study the relationship between force, mass and acceleration. One useful method is to divide the total mass into two unequal parts and attach the two parts to a string passing over a pulley. This way the acceleration can be small, compared to gravity, and be measured more conveniently than the acceleration of gravity. With small acceleration, air friction is negligible (at least for moderate distances). Two other factors are more problematical: the friction in the pulley bearing and the mass of the pulley. The mass of the pulley problem is minimized by using a small, lightweight plastic pulley. The friction problem is less easy to deal with, and probably accounts for most of the error in this experiment.

PROCEDURE A

1. You will use a pulley which is part of a rotary motion sensor. The computer is programmed to calculate and display or manipulate the position, velocity and acceleration of the objects making the pulley rotate.
2. Attach the rotary motion sensor to the rod provided and use a right angle clamp to attach the rod to a ring stand, near the top. The ring stand itself is fastened to the edge of the lab table with a C-clamp. Thread a 1.5 to 2 meter long string onto the pulley and hang a 50-g mass on each end of the string. Note that the hangers stop after being given a slight push, because of friction. Plug the yellow plug of the Rotary Sensor into Digital Channel One (DC 1) and the other plug into DC 2.
3. Turn on the black computer interface box, and then turn on the computer. Double click on the Data Studio icon. When you have the data studio screen, select "Create an experiment" and scroll down to select "Rotary Motion Sensor". Double click on the rotary motion sensor (on the Experiment Setup window), then double click on the rotary motion sensor icon under the DC1 and 2 plugs. Click the "Rotary Motion Sensor" tab. Under Linear Calibration, choose Large Pulley (groove) instead of Rack. Now, select the measurement tab. On the list, unclick Angular Position, then

click on “Acceleration, Ch1&2 (m/s/s)”, then choose “Velocity, Ch1&2”, and finally click OK.

4. Double-click on the Graph icon under the Display space (below the data window). This will activate either an acceleration or velocity graph. Drag the other quantity onto the icon for graph 1. (So if the acceleration graph appears, drag the word “velocity” onto graph 1.) This process will connect the two graphs.
5. In this first part of the experiment the total mass ($m_1 + m_2$) will always be the same. Masses to be used are in Data Table A. Set the first value of masses on the hangers. Don’t forget that the hangers are 50g, so if the data calls for $m_1 = 350$ g, you have to add only 300 g to the hanger.
5. Place a piece of foam on the floor at the spot where m_1 will hit the floor. Raise m_1 even with m_2, stop any swinging motion, click “Start” on the computer and then release m_1. When m_2 (the ascending mass) arrives at the top, one person should catch it, in case it comes loose from the string, so it doesn’t fall to the ground. A partner should immediately click the STOP button.
6. Click on the graph window; click the autoscale button (looks like a white box with showing a smaller box along with an arrow pointing to the right corner, just left of the “positive magnifying glass” and right below the Start button). Now, examine the graph. If the two masses collided when they passed each other, you should see a region of near constant acceleration, and then a spike in acceleration at the collision. Use the mouse to click and draw a rectangle around a section of the graph where the acceleration is constant (or nearly so). There may be a delay in the rectangle appearing, and you must have an arrow, not a hand as the cursor to draw the rectangle. Make sure the rectangle completely encloses all the data in its region. Then click the down arrow on the statistics button (marked Σ, near the center top of the graph window). Select “mean”, for average. On the velocity graph, highlight the same region as on the acceleration graph; to display the slope, click on the down arrow on the Fit box (left of the Calculator box), and select linear fit. A window display on the graph then pops up.
7. Record the average acceleration (in cm/s^2) in Data Table A for the first pair of masses. You may either record the data on a printed data table in this printed copy of directions or in the Data Table 4A saved as an Excel spreadsheet on your lab computer.
8. Repeat procedures 6 and 7 for the other 4 pairs of masses on Data Table A.
9. Fill in the rest of Data Table A, either by calculation on your calculator or by using Excel spreadsheet. Use F_{net} (dyne) = $\Delta m(g) * 980(cm/s^2)$. If you use the Excel spreadsheet to do calculations, show in your Data and Calculation section of lab report what you typed into the spreadsheet to do the calculations, for each different calculation. Also show one calculation (of each different type), to verify the spreadsheet is calculating correctly. If you do not use the spreadsheet, show your sample calculations in the Data and Calculation section of lab report.
10. Plot a graph of F_{net} vs a, and find the slope. You may do this by hand, or by using the Excel spreadsheet graphing function, as described in the “graph instructions exp 2” file. The directions “graph instructions” are found in the “shared” file under Neighborhood Network. Do this procedure (graphing) only after you have completely filled in both data tables. This graphing may be done here in the lab, or at home, or in Academic Computing center. If you do graphing by hand, be sure to use one page for each graph, and choose a scale so the graph fills up the whole page. If

you do the graph here on the computer, remember to select “print preview” under file to fit graphs and data tables on one page. Remember also to type your names on top of data table, in boxes A1 to A4. (The change will be that the “graph instructions exp 2 are written for position or velocity vs time, while you are doing F vs a. Also, choose linear fit.)

11. Compare the value of the slope with the total mass of Data Table A. Find the percent error.

PROCEDURE B

12. In the next part of the experiment the net force will always be the weight of 40 g. The masses to be used are in Data Table B. Fill in the data table for all pairs of masses, with the same choice as above for calculated parts (either by hand or with the Excel spreadsheet). Use $m = m_{total} = m_1 + m_2$.
13. Plot a graph of m vs 1/a and calculate the slope.
14. Compare the value of the slope with the value of net force of Data Table B. Find the percent error.

QUESTIONS

1. Pick one set of data from Data Table A and calculate the theoretical acceleration for this set. Compare this theoretical acceleration to the experimental acceleration for this set of data. What is the percent error? Explain the reason for the difference, including the direction of the difference (is a_{theory} greater or less than a_{exp} and why?).
2. What is the advantage of drawing a graph and finding a slope, rather than doing only calculations, say of all the a_{theory} and a_{exp} values in Data Table A?

DATA TABLE A

m_1(g)	m_2(g)	Δm(g)	F_{net}(dynes)	a(cm/s^2)
350	260			
340	270			
330	280			
320	290			
310	300			

From graph: m = ___________

$m_{actual} = m_1 + m_2 =$ ___________

DATA TABLE B

m_1(g)	m_2(g)	Δm(g)	a(cm/s^2)	m(g)	1/a(s^2/cm)
200	160				
300	260				
400	360				
500	460				
600	560				

From Graph: F_{net} = ___________

$F_{net\ actual} = (\Delta m)g =$ ___________