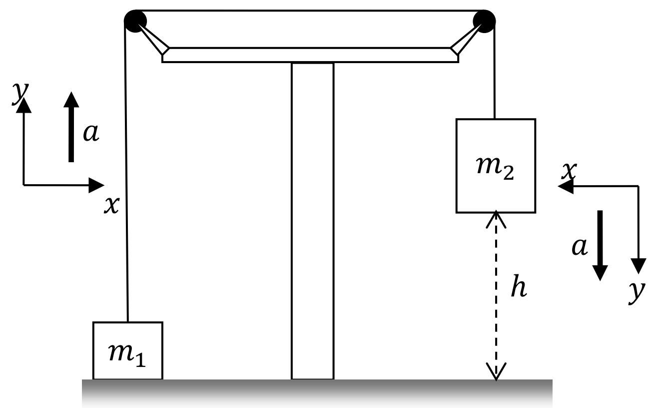
SUGGESTED ORAL PRESENTATION IDEAS

Easiest options (1-3) should go to groups who did air resistance or oscillations.

More theory heavy options (4, 9, & 10) should go to runners, tennis ball, & ball down ramp to magnet.

OPTION 1: Atwood's Machine with Smart Pulley

Test: Does Newton's 2nd Law accurately predict the acceleration of a three mass system?



Theory: Include an FBD of each object. List force equations for each object, and the derive equation for a_{th}. Explain what assumptions are made when we assume all m's have same a. Explain what m's make $a_{th} = 0$. Explain what we expect for a_{th} when m_1 or m_2 is much bigger than all other masses in the problem.

Procedure: Use a smart pulley as one of the pulleys to get the data done in a timely manner.
Get vt-data using data studio for each mass combination.
There will be 7 possible values for m_1 & m_2. Use $50, 75, 100, 125, 150, 175$ & 200 g.
Notice this gives a total of 49 data sets of velocity and time (but 7 data sets should have zero acceleration).
You have the easiest theory but the most data collection so just tough it out and get it over with.
Note: sometimes the system will accelerate negatively.

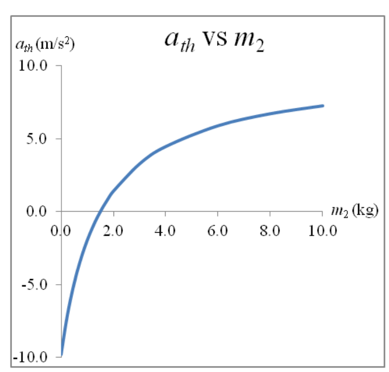
Record all masses used in each trial with a balance.
For one trial, create a vt-plot to use in your talk (to explain how you determined acceleration).
For the rest get acceleration using the LINEST function (see lab manual appendices).
Make a contour plot of your experimental data (see the table of contents of this manual…last lab in this manual).
Make a theoretical contour plot as well.
Get a % precision estimate using $\frac{\delta slope}{slope}$ from the LINEST function.
Get % difference for each data point.
Also get the *absolute value* of the percent difference for each data point.

Data/Graph:

- For single trial, show a vt-plot to explain how you obtained acceleration.
- For a single value of m_1, show a Type II graph (theory as smooth line without data points, experiment as points without line) of a vs m_2. Change the data points from dots to cross-hairs using error bars (see the help file and discuss with your instructor).
- Also compare the theoretical and experimental contour plots.

Conclusions: Tell the audience if the Newton's 2nd Law is in good agreement with your experimental results that used kinematics. This is probably true if your average % difference is less than your average % error.

Note: I plotted a_{th} vs m_2 for $m_1 \approx 1.5$ kg. Notice the plot is non-linear and asymmetric. Notice the value of acceleration when m_2 is much less than or much more than m_1! Your curve will look different due to different values.



Since the force equations are so easy on this one, add in a Contour plot in MATLAB showing a_{th} for a wide range of both m_1 & m_2 values.
More about this on the next page.

To make the contour plots:
First collect all *experimental* data in the following form in Excel (my data is totally fake).

					m_2			
		50	**75**	**100**	**125**	**150**	**175**	**200**
	50	0.07	1.83	2.66	4.19	5.27	5.28	6.74
	75	-1.74	-0.51	0.84	2.87	3.38	3.89	4.22
	100	-2.95	-1.87	-0.27	1.74	1.45	2.96	3.78
m_1	**125**	-4.04	-2.50	-0.92	-0.12	1.50	2.11	2.35
	150	-5.31	-3.99	-2.10	-0.53	0.54	0.93	0.61
	175	-4.66	-4.37	-2.95	-2.17	-1.11	0.10	0.47
	200	-6.06	-5.15	-3.13	-1.74	-1.92	-0.93	-0.30

The numbers in red are simply column headings.
The numbers in black are the acceleration values.

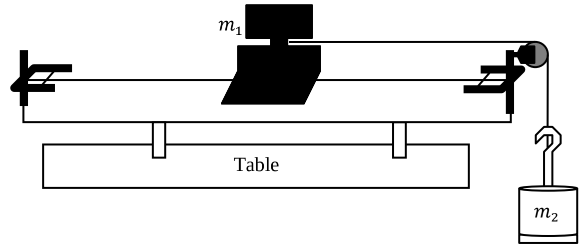
You should also create a set of *theoretical* values as well.
A screen shot of the theoretical calculation I used is shown below.
Notice the formula I typed in cell **N3**…
Notice N$2 implies the *row* 2 is locked (as you fill *down*) but the *column* is free to vary (as you fill *right*).
Notice $B3 implies the *column* B is locked (as you fill *right*) but the *row* is free to vary (as you fill *down*).
I expect you to fill in the empty cells using your formula!!!

	L	M	N	O	P	Q	R	S	T
1					m_2				
2			50	75	100	125	150	175	200
3			=9.8*(N$2-$B3)/(N$2+$B3)		.27	4.20	4.90	5.44	5.88
4		75	-1.96	0.00	1.40	2.45	3.27	3.92	4.45
5		100	-3.27	-1.40					
6	m_1	125	-4.20	-2.45					
7		150	-4.90	-3.27					
8		175	-5.44	-3.92					
9		200	-5.88	-4.45					

Once the numbers are in this state, you can copy and paste the black values only into a new variable in MATLAB.
Once you reach this state, I can help you one-on-one.
Alternatively, open MATLAB and look near the top middle of the screen for "New Variable".
Click on new variable to open a spreadsheet.
Cut and paste your data into the spreadsheet (and rename the variable).
Click around until you find the "Command Window".
In the command window, type "contourf(your_variable_name)".
From there click around to find axis formatting options. Be certain to fix the axis labels (look for "Ticks").

OPTION 2: Newton's Law Part I

Test: Does Newton's 2nd Law accurately predict the acceleration of a two mass system?



Theory: Include an FBD of each object, force equations for each object, and the derive equation for a_{th}. Explain how a_{th} makes sense in the two obvious special cases $m_2 \gg m_1$ & $m_2 \ll m_1$.

Procedure: Adjust the feet of the track (or add shims) until it is level.
You'll know it is level if a glider remains motionless.
For each mass combo, determine a_{exp} using a photogate pulley (Smart Pulley) to record vt-data.
Record m_1 & m_2 used in each trial **with a balance**. Don't forget to include the mass hanger!
I expect a table of vt-data for 3 possible values of m_1 with 11 values of m_2.
I would use $m_1 \approx 200, 300, \& \ 400$ g with $m_2 \approx 2, 4, \ldots 20$ g.
Note: you have a pretty easy theory and but significant data collection. Just tough it out and get it done.

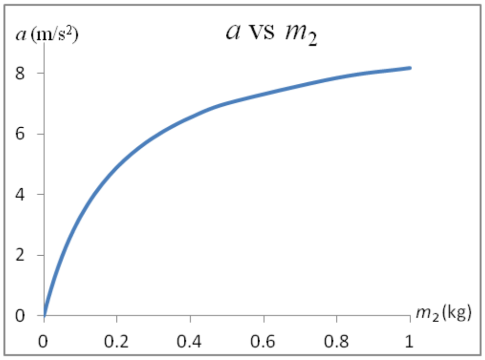
For one trial, create a vt-plot to use in your talk (to explain how you determined acceleration).
For the rest get acceleration using the LINEST function (see lab manual appendices).
Make a contour plot of your experimental data (see the table of contents of this manual…last lab in this manual).
Make a theoretical contour plot as well.
Get a % precision estimate using $\frac{\delta slope}{slope}$ from the LINEST function.
Get % difference for each data point.
Also get the *absolute value* of the percent difference for each data point.

Data/Graph:

- For single trial, show a vt-plot to explain how you obtained acceleration.
- For a single value of m_1, show a Type II graph (theory as smooth line without data points, experiment as points without line) of a vs m_2. Change the data points from dots to cross-hairs using error bars (see the help file and discuss with your instructor).
- Also compare the theoretical and experimental contour plots.

Conclusions: Tell the audience if the Newton's 2nd Law is in good agreement with your experimental results that used kinematics. This is probably true if % difference is less than % error.

As check on your work I provided a theoretical plot of for $m_1 = 200$ g. Notice the acceleration asymptotically approaches g. Your curve will look different due to different values. Ideally you could generate two similar plots using your two different values for m_1. These could be shown in the theory portion of your talk. If you make the plots, try to point out the difference in the rate at which the curve approaches the asymptote. Whoops…notice that I missed changing the horizontal axis label into the same font as everything else!



Since the force equations are so easy on this one, add in a Contour plot in MATLAB showing a_{th} for a wide range of both m_1 & m_2 values.
More about making the contour plots on the next page.

To make the contour plots:
First collect all *experimental* data in the following form in Excel (my data is totally fake).

						m_2					
		2	4	6	8	10	12	14	16	18	20
	200	0.17	0.20	0.21	0.15	0.55	0.41	0.71	0.58	0.76	0.94
m_1	300	0.01	0.01	0.16	0.03	0.35	0.27	0.39	0.33	0.54	0.41
	400	0.21	0.18	0.20	0.06	0.36	0.27	0.47	0.35	0.45	0.70

The numbers in red are simply column headings.
The numbers in black are the acceleration values.

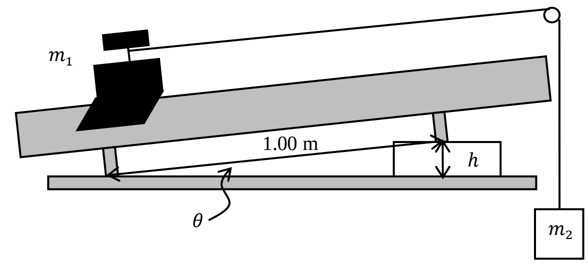
You should also create a set of *theoretical* values as well.
A screen shot of the theoretical calculation I used is shown below.
Notice the formula I typed in cell **N3**…
Notice Q$2 implies the *row* 2 is locked (as you fill *down*) but the *column* is free to vary (as you fill *right*).
Notice $B3 implies the *column* B is locked (as you fill *right*) but the *row* is free to vary (as you fill *down*).
I expect you to fill in the empty cells using your formula!!!

	O	P	Q	R	S	T	U	V	W	X	Y	Z
1							m_2					
2			2	4	6	8	10	12	14	16	18	20
3	=9.8*(Q$2)/(Q$2+$B3)				29	0.38	0.47	0.55	0.64	0.73	0.81	0.89
4	m_1	300	0.06	0.13	0.19							
5		400	0.05	0.10	0.14							

Once the numbers are in this state, you can copy and paste the black values only into a new variable in MATLAB.
Once you reach this state, I can help you one-on-one.
Alternatively, open MATLAB and look near the top middle of the screen for "New Variable".
Click on new variable to open a spreadsheet.
Cut and paste your data into the spreadsheet (and rename the variable).
Click around until you find the "Command Window".
In the command window, type "contourf(your_variable_name)".
From there click around to find axis formatting options. Be certain to fix the axis labels (look for "Ticks").

OPTION 3: Newton's Law Part II

Test: Does Newton's 2nd Law accurately predict the acceleration of a two mass system?



Theory: Include an FBD of each object, force equations for each object, and the derive equation for a_{th}. Explain how a_{th} makes sense in the two obvious special cases $m_2 \gg m_1$ & $m_2 \ll m_1$. Explain why the size of m_2 relative to $m_1 \sin\theta$ indicates the direction of acceleration.

Procedure: Adjust the feet of the track (or add shims) until it is level.
You'll know it is level if a glider remains motionless.
ONCE IT IS LEVELED, then begin to raise the angle.
Use several different angles in your experiment (*approximately* $0°, 1°, \dots, 5°$).
We may need to cut some shims (or use some slotted masses).
Think, the required shim heights are given by $\sin\theta = \frac{h}{1.00\text{ m}}$ (see figure).
For each mass combo, determine a_{exp} using a photogate pulley (Smart Pulley) to record vt-data.
Record m_1 & m_2 used in each trial **<u>with a balance</u>**. Don't forget to include the mass hanger!
Get vt-data for 6 possible angles (*record actual angle using shim height*) with $m_1 \approx 200$ g.
For each angle use 6 values of m_2 $(0, 4, 8, \dots, 20\text{ g})$.
Note: you have a pretty easy theory and but significant data collection. Just tough it out and get it done.
BE CAREFUL WITH THE LARGE ANGLES!

- Try to ensure the equipment survives for next year by catching the glider without it smashing into things.
- Watch for the hose bumping into the table when you start angling up!

For one trial, create a vt-plot to use in your talk (to explain how you determined acceleration).
For the rest get acceleration using the LINEST function (see lab manual appendices).
Make a contour plot of your experimental data (see the table of contents of this manual…last lab in this manual).
Make a theoretical contour plot as well.
Get a % precision estimate using $\frac{\delta slope}{slope}$ from the LINEST function.
Get % difference for each data point.
Also get the *absolute value* of the percent difference for each data point.

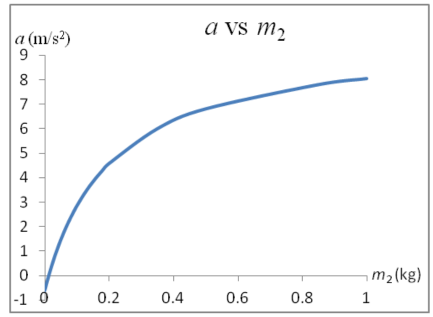
Data/Graph:

- For single trial, show a vt-plot to explain how you obtained acceleration.
- For a single value of θ, show a Type II graph (theory as smooth line without data points, experiment as points without line) of a vs m_2. Change the data points from dots to cross-hairs using error bars (see the help file and discuss with your instructor).
- Also compare the theoretical and experimental contour plots.

Conclusions: Tell the audience if the Newton's 2nd Law is in good agreement with your experimental results that used kinematics. This is probably true if % difference is less than % error.

On the next page I included a sample plot made from fake data…

As check on your work I made a fake theoretical plot for $h = 6.35$ cm & $m_1 = 200$ g. Notice the acceleration asymptotically approaches g. Ideally you could generate a similar plot using your values for m_1 and h. This could be shown in the theory portion of your talk. Your curve will look different due to different values.



Since the force equations are so easy on this one, add in a Contour plot in MATLAB showing a_{th} for a wide range of both m_1 & m_2 values.
More regarding contour plots on the next page…

To make the contour plots:

First collect all *experimental* data in the following form in Excel (my data is totally fake).

		m_2				
		4	8	12	16	20
	0	0.13	0.19	0.42	0.74	0.88
	1	0.22	0.23	0.38	0.42	0.59
	2	0.10	0.04	0.40	0.38	0.49
θ	3	-0.56	-0.25	0.02	0.37	0.37
	4	-0.42	-0.32	-0.26	0.30	0.29
	5	-0.62	-0.47	-0.34	-0.25	0.16

The numbers in red are simply column headings.
The numbers in black are the acceleration values.

You should also create a set of *theoretical* values as well.
A screen shot of the theoretical calculation I used is shown below.
Notice the formula I typed in cell **L3**…
Notice L$2 implies the *row* 2 is locked (as you fill *down*) but the *column* is free to vary (as you fill *right*).
Notice $K3 implies the *column* B is locked (as you fill *right*) but the *row* is free to vary (as you fill *down*).
I expect you to fill in the empty cells using your formula!!!

	H	I	J	K	L	M	N	O	P
1							m_2		
2					4	8	12	16	20
3	=9.8*(L$2-200*SIN(RADIANS($K3)))/(L$2+200)								0.89
4				1	0.02	0.21	0.39	0.57	0.74
5				2	-0.14	0.05			
6			θ	3	-0.31	-0.12			
7				4	-0.48	-0.28			
8				5	-0.65	-0.44			

Once the numbers are in this state, you can copy and paste the black values only into a new variable in MATLAB.
Once you reach this state, I can help you one-on-one.
Alternatively, open MATLAB and look near the top middle of the screen for “New Variable”.
Click on new variable to open a spreadsheet.
Cut and paste your data into the spreadsheet (and rename the variable).
Click around until you find the “Command Window”.
In the command window, type “contourf(your_variable_name)”.
From there click around to find axis formatting options. Be certain to fix the axis labels (look for “Ticks”).

OPTION 4: Circular Motion Using CENCO Quantitative Centripetal Force Apparatus

Warning: This experiment can cause a sizeable mass to hit your face at high speeds. Discuss appropriate safety precautions with your instructor prior to operation.

Test: Does Newton's 2nd Law accurately model the acceleration of a body in circular motion?

Theory: For a mass m in uniform circular motion the net force towards the center (F_c) is given by

$$F_c = m\frac{v^2}{r}$$

where v is the speed of the mass and r is the radius of the circular motion.

Consider first the system in Figure 1a which is <u>at rest</u>. The indicator rod is set to a fixed position. Balancing mass m_b is adjusted until the pointer mass is directly above the indicator rod. When the pointer mass is in equilibrium above the indicator rod, we know that the force exerted by the spring is equivalent to the balancing weight ($F_{spring} = m_b g$).

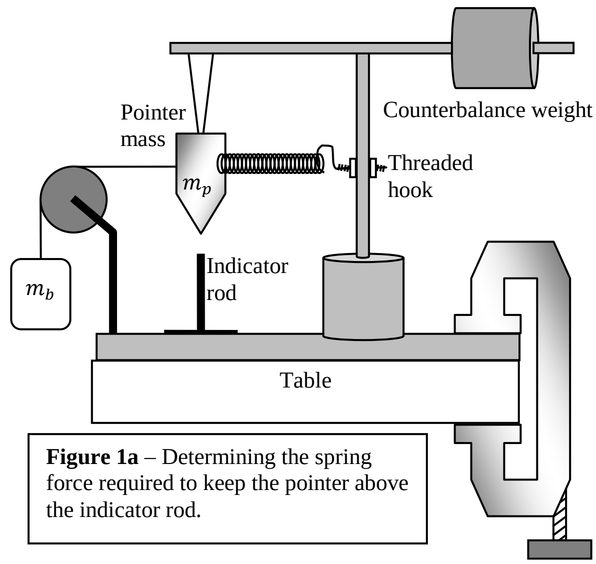


Figure 1a – Determining the spring force required to keep the pointer above the indicator rod.

Now consider the system in Figure 1b which is <u>rotating</u>. The system is now caused to rotate in such that the pointer mass remains directly above the indicator rod. Furthermore, the spring force is the only force exerted towards the center of circular motion. This gives

$$F_{spring} = m_p\frac{v^2}{r}$$

where m_p is the pointer mass, r is the distance from the center of the shaft to the indicator rod, and v is the speed at which m_p moves. For uniform circular motion with period $\mathbb{T}$ one finds

$$v = \frac{2\pi r}{\mathbb{T}}$$

Notice the spring in Figure 1b is stretched the same as in Figure 1a so one still knows $F_{spring} = m_b g$. Verify that combining these facts gives

$$\boldsymbol{m_b g = m_p\frac{v^2}{r}}$$

This gives a way to directly compare the required centripetal force ($m_b g$) to the required speed as predicted by Newton's 2nd Law as applied to uniform circular motion.

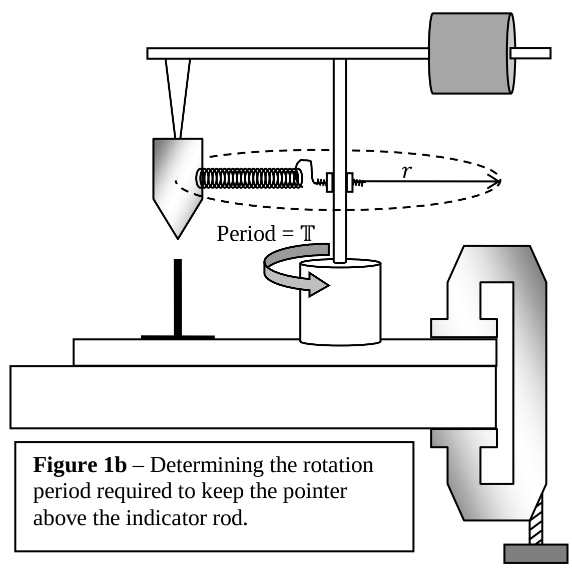


Figure 1b – Determining the rotation period required to keep the pointer above the indicator rod.

Procedure: Lock the indicator rod in place; measure and record r. Adjust the nuts on the threaded hook such that almost none of the threaded hook extends out of the center shaft on the side opposite the spring. Measure and record the balancing mass m_b required to align m_p with the indicator rod. Remove the balancing mass before rotating the shaft.

Now spin the center shaft in such a way as to keep m_p directly above the indicator rod. You will likely have to give the center shaft a small twist every revolution or two to ensure the period of rotation remains roughly constant.

Tip: when the pointer mass first passes directly over the indicator rod start counting **from 0 to 10**. This will give you 10 orbits. Take the time for 10 orbits with a stopwatch. Divide by 10 to get the period. This average period should have acceptable error. Note: we've tried doing the experiment with a photogate and errors were much worse.

Now adjust the nuts on the threaded hook such that a slightly greater mass m_b is required to balance the pointer mass above the indicator rod. Repeat the experiment to obtain both m_b & $\mathbb{T}$. Continue adjusting the nuts on the threaded hook until you obtain m_b and $\mathbb{T}$ data for at least 7-10 different nut positions on the threaded hook. You can then make a plot several plots. **WARNING:** trying to measure velocity directly with the photogate often gives bad data. Measure *period* with the photogate…*not velocity*.

Data/Graph: On one plot we want to plot the raw data in the experiment versus the predicted data from theory. The raw data is m_b on the x-axis and T on the y-axis.

To create the theoretical data, first rearrange $\boldsymbol{m_b g = m_p \frac{v^2}{r}}$ to include the period instead of v.

Hint: use $v = \frac{circumference}{period}$.

Then, solve your new equation for T on the left side of the equation. You should end up with

$$\boldsymbol{T_{th} = \frac{(a\ bunch\ of\ crap)}{m_b^{1/2}}}$$

In my experience, speed is more intuitive to students than period when discussing circular motion.
Because of this, use your experimentally determined *periods* to calculate the experimental *velocity* for each trial.
If we do this we could make a table of v^2 versus m_b.
Here m_b is the independent variable and lies on the x-axis once again.
Rearranging our equation again gives

$$\boldsymbol{v^2 = \frac{rg}{m_p} m_b}$$

This should be a linear equation if v^2 is on the y-axis and m_b is on the x-axis.
The slope of a v^2 versus m_b should be

$$slope = \frac{rg}{m_p}$$

Note: don't forget to determine the units of the slope.
Solving the above equation for g gives

$$\boldsymbol{g_{exp} = \frac{m_p}{r}(slope)}$$

This gives us a test!
If the value of g_{exp} obtained from the slope of your v^2 versus m_b plots is close to the accepted value of 9.8 m/s^2 then it must be appropriate to use $a_c = \frac{v^2}{r}$ in Newton's 2nd Law problems involving uniform circular motion.

Summary of required plots on the next page…

Summary of required plots:

1) Get one plot of raw data (T vs. m_b) with theoretical line (smooth line, no points) and experiment (points with error bars only). Do NOT use a trendline on this plot.
2) Get one plot of v^2 vs. m_b. Use a trendline (instead of a theoretical curve) on this plot. Use the slope to get g_{exp} and compare to the accepted value. Include error bars on your experimental points and use LINEST to get the error in the slope. Propagate this error through to g_{exp} so we know how crappy your data is (1%, 2%, etc).
3) Note: When getting data you get seven trials for each of two different fixed radii.
   You should have a T vs m_b & v^2 vs m_b plot for each data set (giving **four** total plots).

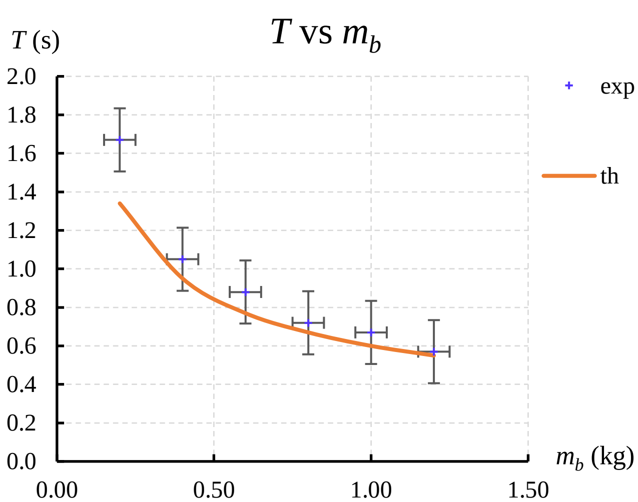
Conclusions: Compare % difference to % error for your value of g_{exp}. If the % difference is less than the % error then the use of $a_c = \frac{v^2}{r}$ and Newton's 2nd Law accurately model uniform circular motion. State if Newton's 2nd law accurately models the acceleration of a body in circular motion. Discuss errors & limitations inherent in using this device. Discuss ways one might minimize these errors or re-design the apparatus to produce better results.

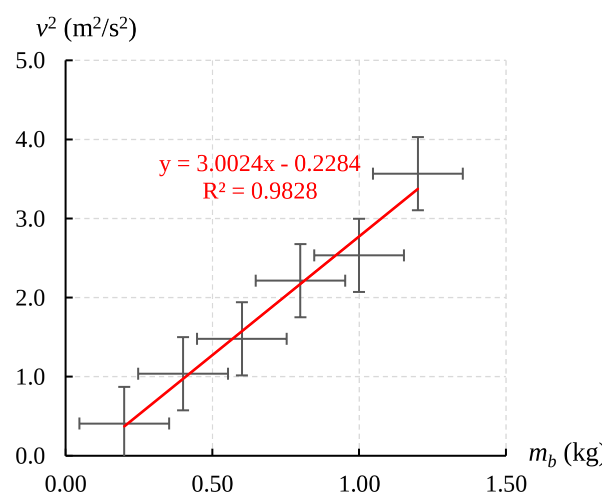
Fake data is shown below to give you a better idea of the kind of thing you might expect.

r (m)	m_p (kg)
0.17	0.525

m_b (kg)	T_{exp} (s)	T_{th} (s)	v_{exp} (m/s)	v_{exp}^2 (m^2/s^2)
0.2	1.67	1.34	0.64	0.408
0.4	1.05	0.95	1.02	1.037
0.6	0.88	0.77	1.22	1.479
0.8	0.72	0.67	1.49	2.214
1	0.67	0.6	1.59	2.534
1.2	0.57	0.55	1.89	3.567

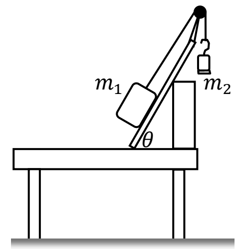
Your curves will look different due to different values.





OPTION 5: Static Phriction Phreaque-Out

Test: Does Newton's 2nd Law accurately predict the behavior of a two mass system?



Consider the figure shown at right. Mass m_1 is a hockey puck while mass m_2 is a mass hanger with additional slotted weights. Determine the largest m_2 that can be placed on the system while still allowing the puck to remain at rest. Use angles of 0.0° up to 72.0° in 8.0° increments. Test the same angle at least five different spots on the board to get an average value of m_2 for each angle. Watch out! Make sure the string is always parallel to the board by adjusting the pulley.

Do your FBDs and force equations. Solve the equations in two ways: 1) solve for m_2 and 2) solve for μ_s.
Assume the accepted value for $\mu_s = 0.70$. Use that μ_s to predict theoretical values of m_2 for each θ.
Plot m_2 versus θ.
Also determine the experimental value of μ_s for each angle. Determine the average experimental μ_s.

Theory/Procedure: Will definitely need more than one slide for all this…Show a photo of the apparatus. Draw an FBD for each mass. Write the force equations. Solve the equations algebraically for m_2 to show the class how m_2 should change as θ changes. Also solve the force equation (algebraically) for μ_s. Then plug in numbers and get values for $\mu_s$for each trial. Also determine an average value of $\mu_s$from all trials.

Describe how you determined the values of m_2 for each trial. How many trials did you perform at each θ to get an average? Determine error estimates for each method based on the range of values for m_2 obtained for each θ. Describe how your experimental procedure to measure the values of a.

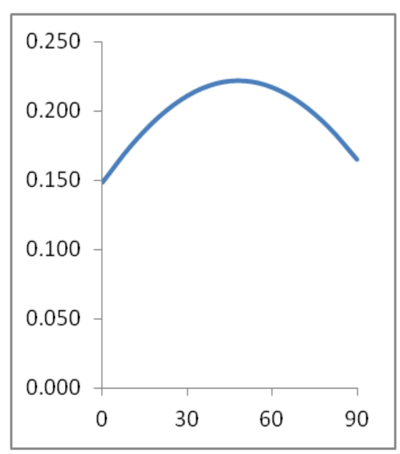
Data/Graph: You should be able to make a plot of m_2 versus θ using your data. You should also be able to come up with theoretical values based on the force equation you found. Create a graph similar to the one in the lab manual appendix under Sample Graph Type II. The theory should show a smoothed line with no points while the experiment should have data points indicated by dots. Put error bars on your graph using the MS Excel help file or by having a discussion with your instructor.

Conclusions: Does Newton's 2nd law accurately predict the values of m_2 required to cause the onset of slipping? Does the average value obtained for μ_s agree with accepted values (hint: compare using an internet search)? Discuss both your percent errors and percent differences to support the validity of your claims.

For reference I made a theoretical plot of m_2 vs θ for a puck mass of 165 g and assuming $\mu_s = 0.9$. Something similar might be useful in your talk to explain the theoretical equations. Notice that on level ground $m_2 < m_1$; this is an artifact of $\mu_s < 1$. Also notice at 90° the two masses must equal as friction doesn't come into play when the board is straight up and down!

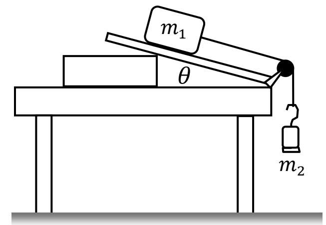
Your curve will look different due to different values.

μ	m_1 (kg)
0.9	0.165
θ (°)	m_2 (kg)
0	0.149
10	0.175
20	0.196
30	0.211
40	0.220
50	0.222
60	0.217
70	0.206
80	0.188
90	0.165



OPTION 6: Static Phriction Phreaque-Out

Test: Does Newton's 2nd Law accurately predict the behavior of a two mass system?



Consider the figure at right. Mass m_1 is a hockey puck while mass m_2 is a mass hanger with additional slotted weights. Determine the largest m_2 that can be placed on the system while still allowing the puck to remain at rest. Use angles of 0.0° up to θ_{crit} in 5.0° increments. Note: the critical angle can also be recorded as a data point since $m_2 = 0$ for θ_{crit}. The critical angle is obtained by the method described in class. Test the same angle at least five different spots on the board to get an average value of m_2 for each angle. Watch out! Make sure the string is always parallel to the board by adjusting the pulley.

Do your FBDs and force equations. Solve the equations in two ways: 1) solve for m_2 and 2) solve for μ_s.
Assume the accepted value for $\mu_s = 0.70$. Use that μ_s to predict theoretical values of m_2 for each θ.
Plot m_2 versus θ.
Also determine the experimental value of μ_s for each angle. Determine the average experimental μ_s.

Theory/Procedure: Will definitely need more than one slide for all this…Show a photo of the apparatus. Draw an FBD for each mass. Write the force equations. Solve the equations algebraically for m_2 to show the class how m_2 should change as θ changes. Also solve the force equation (algebraically) for μ_s. Then plug in numbers and get values for μ_s for each trial. Also determine an average value of μ_s from all trials.

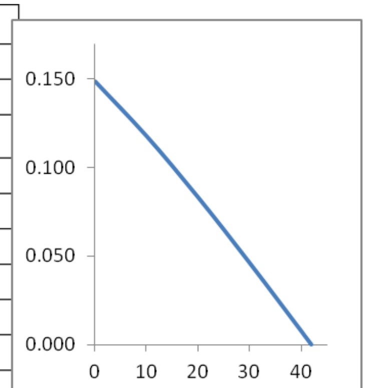
Describe how you determined the values of m_2 for each trial. How many trials did you perform at each θ to get an average? Determine error estimates for each method based on the range of values for m_2 obtained for each θ. Describe how your experimental procedure to measure the values of a.

Data/Graph: You should be able to make a plot of m_2 versus θ using your data. You should also be able to come up with theoretical values based on the force equation you found. Create a graph similar to the one in the lab manual appendix under Sample Graph Type II. The theory should show a smoothed line with no points while the experiment should have data points indicated by dots. Put error bars on your graph using the MS Excel help file or by having a discussion with your instructor.

Conclusions: Does Newton's 2nd law accurately predict the values of m_2 required to cause the onset of slipping? Does the average value obtained for μ_s agree with accepted values (hint: compare using an internet search)? Discuss both your percent errors and percent differences to support the validity of your claims.

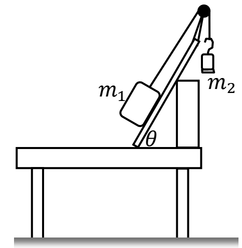
For reference I made a theoretical plot of m_2 vs θ for a puck mass of 165 g while assuming $\mu_s = 0.9$. Something similar might be useful in your talk to explain the theoretical equations. Notice that on level ground $m_2 < m_1$ (an artifact of $\mu_s < 1$). Also, at 42° notice $m_2 = 0$. This corresponds to the critical angle predicted by $\mu_s = 0.9$! Finally, while not easily noticeable, the slope of the line becomes slightly more negative as the angle increases. This is not a straight line so do not use a linear trendline! Your curve will look different due to different values.

μ	m_1 (kg)
0.9	0.165
θ (°)	m_2 (kg)
0	0.149
10	0.118
20	0.083
30	0.046
40	0.008
41	0.004
42	0.000



OPTION 7: Kinetic Phriction Phreaque-Out
(works best with encoder/smart pulley)

Consider the figure shown at right. Mass m_1 is a hockey puck while mass m_2 is a mass hanger with additional slotted weights. Select m_2 such that the system accelerates up the plane at a reasonable rate for a wide range of angles. Consider using 25.0° to 70.0° in 5.0° increments. Again, before starting, find a single value of m_2 that works for the entire range of angles. Watch out! Make sure the string is always parallel to the board by adjusting the pulley.



For each m_2, determine a_{exp} using a photogate pulley (Smart Pulley) to record vt-data.
For one trial, create a vt-plot to use in your talk (to explain how you determined acceleration).
For the rest get acceleration using the LINEST function (see lab manual appendices).
Assume the accepted value for $\mu_k = 0.40$. Use that μ_k to predict theoretical values of a for each θ.
Plot a versus θ.
Also determine the experimental value of μ_k for each angle. Determine the average experimental μ_k.

Test: Does Newton's 2nd Law accurately predict the behavior of a two mass system?

Theory/Procedure: Will definitely need more than one slide for all this…Show a photo of the apparatus. Draw FBDs for each mass. Write the force equations. Solve the equations algebraically for a to show the class how a should change as θ changes. Also solve the force equation (algebraically) for μ_k. Also show the average value of μ_k from all trials.

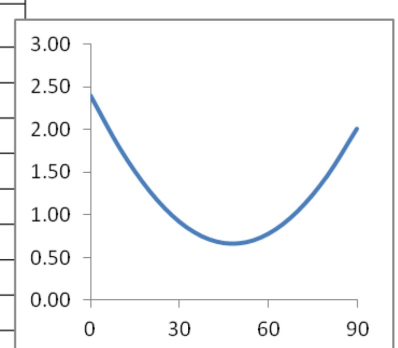
Describe how your experimental procedure to measure the values of a. How many trials did you perform at each θ to get an average? Did you use Tracker, photogates, or stopwatch? Give a few details on your technique as not everyone used the same technique. Determine error estimates for each method based on the range of values for m_2 obtained for each θ. Determine an error estimate for your average value of μ_k.

Data/Graph: You should be able to make a plot of a versus θ using your data. You should also be able to come up with theoretical values based on the equation you found. Create a graph similar to the one in the lab manual appendix under Sample Graph Type II. The theory should show a smoothed line with no points while the experiment should have data points indicated by dots. Put error bars on your graph using the MS Excel help file or by having a discussion with your instructor.

Conclusions: Does Newton's 2nd law accurately predict the values of a for each angle? Does the value obtained for μ_k agree with accepted values (hint: compare using an internet search)? Discuss both your percent errors and percent differences to support the validity of your claims.

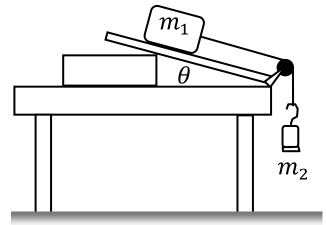
For reference I made a plot of a vs θ using values $m_1 = 165$ g, $m_2 = 250$ g and assuming $\mu_k = 0.4$ or 0.9…I forget which. Something similar might be useful in your talk to explain the theoretical equations. As you increase the angle normal force decreases. Thus, as the angle is increased, the frictional force down the plane is decreasing. At the same time, as the angle increases the component of $m_1 g$ down the plane increases. These two factors cause the unusual graph. Note: while it *looks* like a parabola it is not; do *not* use a polynomial of order 2 trendline on this graph! Your curve will look different due to different values.

μ	m_1 (kg)	m_2 (kg)
0.4 or 0.9?	0.165	0.25
θ (°)	a (kg)	
0	2.40	
10	1.77	
20	1.28	
30	0.92	
40	0.71	
50	0.66	
60	0.78	
70	1.04	
80	1.46	
90	2.01	



OPTION 8: Kinetic Phriction Phreaque-Out Option 2
(works best with encoder/smart pulley)

Consider the figure shown at right. Mass m_1 is a hockey puck while mass m_2 is a mass hanger with additional slotted weights. Select m_2 such that the system accelerates <u>down</u> the plane at a reasonable rate for a wide range of angles. You'll probably want to use small angles such as 0.0° to 16.0° in 2.0° degree increments. Before starting, find a single value of m_2 that works for the entire range of angles. Watch out! Make sure the string is always parallel to the board by adjusting the pulley.



For each m_2, determine a_{exp} using a photogate pulley (Smart Pulley) to record vt-data.
For one trial, create a vt-plot to use in your talk (to explain how you determined acceleration).
For the rest get acceleration using the LINEST function (see lab manual appendices).
Assume the accepted value for $\mu_k = 0.4$. Use that μ_k to predict theoretical values of a for each θ.
Plot a versus θ.
Also determine the experimental value of μ_k for each angle. Determine the average experimental μ_k.

Test: Does Newton's 2nd Law accurately predict the behavior of a two mass system?

Theory/Procedure: Will definitely need more than one slide for all this…Show a photo of the apparatus. Draw FBDs for each mass. Write the force equations. Solve the equations algebraically for a to show the class how a should change as θ changes. Also solve the force equation (algebraically) for μ_k. Then plug in numbers and get values for μ_k for each trial. Also determine an average value of μ_k from all trials.

Describe how your experimental procedure to measure the values of a. How many trials did you perform at each θ to get an average? Did you use LINEST? Give a few details on your technique as not everyone used the same technique. Determine error estimates for each method based on the range of values for m_2 obtained for each θ. Determine an error estimate for your average value of μ_k.

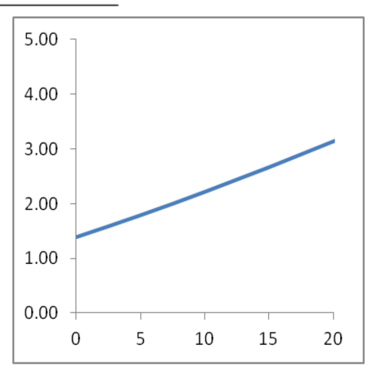
Data/Graph: You should be able to make a plot of a versus θ using your data. You should also be able to come up with theoretical values based on the equation you found. Create a graph similar to the one in the lab manual appendix under Sample Graph Type II. The theory should show a smoothed line with no points while the experiment should have data points indicated by dots. Put error bars on your graph using the MS Excel help file or by having a discussion with your instructor.

Conclusions: Does Newton's 2nd law accurately predict the values of a for each angle? Does the value obtained for μ_k agree with accepted values (hint: compare using an internet search)? Discuss both your percent errors and percent differences to support the validity of your claims.

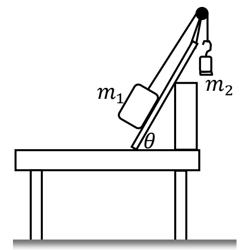
For reference I made a theoretical plot of a vs θ using values $m_1 = 165$ g, $m_2 = 200$ g and assuming $\mu_k = 0.4$. Something similar might be useful in your talk to explain the theoretical equations. This is a challenging experiment because we see the acceleration is extremely sensitive to a small change in angle. Also, while the graph appears linear it is not. Do not use a linear trendline on this graph.

Your curve will look different due to different values.

μ	m_1 (kg)	m_2 (kg)
0.4	0.165	0.2
θ (°)	a (kg)	
0	1.38	
5	1.78	
10	2.21	
15	2.67	
20	3.14	
25	3.63	
30	4.13	
35	4.64	



OPTION 9: Static & Kinetic Phriction Phreaque-Out



Consider the top figure shown at right. Mass m_1 is a hockey puck while mass m_2 is a mass hanger with additional slotted weights.

Select a single angle that is significantly greater than the critical angle (perhaps 65.0°).
First determine what value of m_2 causes puts the system on the verge of slipping up the plane.
Use five different spots on the board to get an average value of this critical mass.
Next determine what value of m_2 causes puts the system on the verge of slipping down the plane.
Use five different spots on the board to get an average value of this critical mass.

Choose three small m_2's that cause the system to accelerate down the plane.
Hint: one value of m_2 could be zero.
For each m_2, determine an experimental value for a using a photogate pulley (Smart Pulley) to record vt-data.
For one trial, create a vt-plot to use in your talk (to explain how you determined acceleration).
For the rest get acceleration using the LINEST function (see lab manual appendices).
Choose four large m_2's that cause the system to accelerate up the plane.
Record the acceleration for each large m_2 using one of the methods described below.

Assume accepted values of $\mu_s = 0.7$ & $\mu_k = 0.4$.
Use that μ_s to predict a theoretical value for the critical mass.
Use that μ_k to predict theoretical values of a for each m_2.
Plot a versus m_2 (showing both experimental and theoretical values).
In addition, determine the average experimental μ_s & μ_k.

Test: Does Newton's 2nd Law accurately predict the behavior of a two mass system?

Theory/Procedure: Will definitely need more than one slide for all this…Show a photo of the apparatus. Draw FBDs for each case. You should have four cases: static with friction up the hill, static with friction down the hill, kinetic with friction up the hill, and kinetic with friction down the hill. Write the force equations. Solve the equations algebraically for a to show the class how a should change as m_2 changes. Also solve the force equation for each case (algebraically) for μ_s or μ_k.

Describe your experimental procedure to measure the values of a. How many trials did you perform at each m_2 to get an average? Did you use LINEST? How did you determine the m_2 that would balance the system? Did you try it at the same spot on the board every time or a bunch of random spots? Give a few details on your technique as not everyone used the same technique. Determine error estimates for each method. Determine an error estimate for your average values of μ_s & μ_k.

Data/Graph: You should be able to make a plot of a versus m_2 using your data. You should also be able to come up with theoretical values based on the equation you found. Create a graph similar to the one in the lab manual appendix under Sample Graph Type II. The theory should show a smoothed line with no points while the experiment should have data points indicated by dots. Put error bars on your graph using the MS Excel help file or by having a discussion with your instructor.

Conclusions: Does Newton's 2nd law accurately predict the values of a for each m_2? Do the values obtained for μ_s & μ_k agree with accepted values? Discuss both your percent errors and percent differences to support the validity of your claims.

Note: see the next page for a theoretical plot of what should be happening in your experiment.

I made a fake theoretical plot for reference using $\mu_s = 0.9$, $\mu_k = 0.4$, $m_1 = 0.165$ kg, and $\theta = 65°$.
The plot of a vs m_2 is particularly devious because the theoretical equation for a changes twice!
Think: when the block is sliding you should use μ_k instead of μ_s…

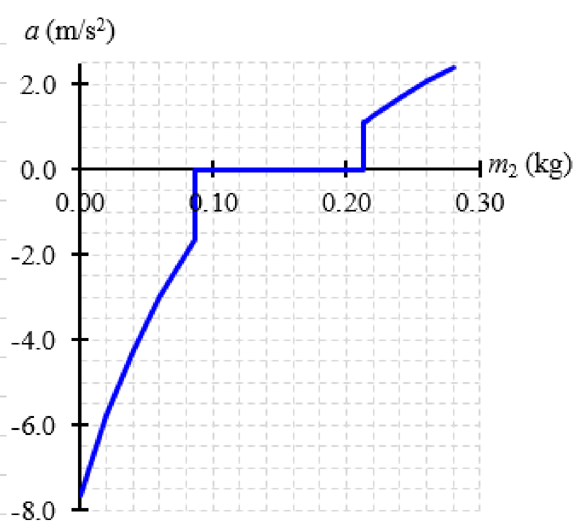
The critical masses $m_2 = 0.087$ kg & 0.212 kg appear notable in the figure.
When the value of m_2 is between those values the system should remain at rest.
Your curve will look different due to different values.

Below the lower limit the system accelerates negatively (down the incline) while above the upper limit the system accelerates positively (up the incline). I hard-coded a minus sign for those values.

Problem **6.29** in the workbook gives a similar situation but with a plot in the solutions.

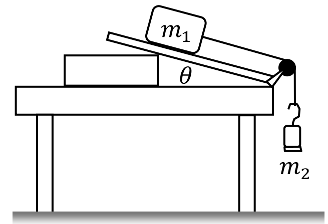
μ_s	μ_k	m_1 (kg)	g (m/s^2)	θ (°)	θ (rad)
0.9	0.3	0.165	9.8	65	1.134

m_2 (kg)	a (m/s^2)
0.000	-7.64
0.020	-5.75
0.040	-4.24
0.060	-2.99
0.080	-1.94
0.086	-1.66
0.0867	**-1.63**
0.0868	**0**
0.087	0
0.212	0
0.2129	**0**
0.213	**1.10**
0.214	1.13
0.220	1.26
0.240	1.68
0.260	2.06
0.280	2.41
0.300	2.73



OPTION 10: Static & Kinetic Phriction Phreaque-Out

Consider the apparatus shown at right. Ensure the string is parallel to the board. Mass m_1 is a hockey puck while mass m_2 is a mass hanger with additional slotted weights.



Select an angle of about 15° and start with $m_2 = 0$.
Gradually increase the mass until the onset of slipping occurs.
Check perhaps 10 different spots on the board.
The *average* value of mass required to cause slipping is the experimental critical mass.

In addition, choose seven different m_2's which cause the system to accelerate down the plane.
For each m_2, determine an experimental value for a using a photogate pulley (Smart Pulley) to record vt-data.
Assume accepted values of $\mu_s = 0.7$ & $\mu_k = 0.4$.
Use that μ_s to predict a theoretical value for the critical mass.
Use that μ_k to predict theoretical values of a for each m_2.
Plot a versus m_2 (showing both experimental and theoretical values).
In addition, determine the average experimental μ_s & μ_k.

Test: Does Newton's 2nd Law accurately predict the behavior of a two mass system?

Theory/Procedure: Will definitely need more than one slide for all this…Show a photo of the apparatus. Draw FBDs for each case. You should have two cases: static friction directed up the plane (acceleration is zero) and kinetic friction directed up the plane (acceleration down the plane). Write the force equations. Solve the equations algebraically for a to show the class how a should change as m_2 changes. Also solve the force equation for each case (algebraically) for μ. Then plug in numbers and get values for μ for each trial.

Describe how your experimental procedure to measure the values of a. How many trials did you perform at each m_2 to get an average? Did you use Tracker, photogates, or stopwatch? How did you determine the m_2 that would balance the system? Did you try it at the same spot on the board every time or a bunch of random spots? Give a few details on your technique as not everyone used the same technique. Determine error estimates for each method. Determine an error estimate for your average value of μ_k.

Data/Graph: You should be able to make a plot of a for each m_2 using your data. You should also be able to come up with theoretical values based on the equation you found. Create a graph similar to the one in the lab manual appendix under Sample Graph Type II. The theory should show a smoothed line with no points while the experiment should have data points indicated by dots. Put error bars on your graph using the MS Excel help file or by having a discussion with your instructor.

Conclusions: Does Newton's 2nd law accurately predict the values of a for each m_2? Do the values obtained for μ_s & μ_k agree with accepted values? Discuss both your percent errors and percent differences to support the validity of your claims.

I made a fake plot of a versus m_2 on the next page to give you an idea of how things might look.

The critical mass $m_2 = 0.0688$ kg is notable in the figure.
For m_2 masses below that value the system should remain at rest.
Your curve will look different due to different values.

μ_s	μ_k	m_1 (kg)	θ (°)	m_{2crit} (kg)
0.7	0.4	0.165	15	0.0688

m_2 (kg)	a (m/s^2)
0	0.0
0.06	0.0
0.068	0.0
0.069	2.0
0.070	2.0
0.100	2.9
0.150	4.0
0.200	4.8
0.250	5.4
0.300	5.9