PHY 111L Activity 4

Newton's Laws of Motion

Name: _____ ID #:_____

Section: _____ Date: _____

Lab Partners: _____ TA initials: _____

Objectives

1. Introduce Newton's 3 Laws of motion
2. Understand how to draw and interpret a free body diagram
3. Use Newton's laws to find the acceleration of an object along level and inclined planes (lab report)
4. Use DataStudio to measure the acceleration for those cases and compare to calculated values

Materials & Resources

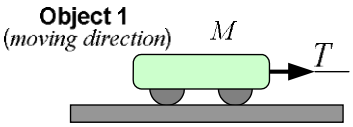
1. Computer with DataStudio and 2 photo gates
2. Dynamics track with cart, protractor, mass set, pulley, string, and a bubble-level

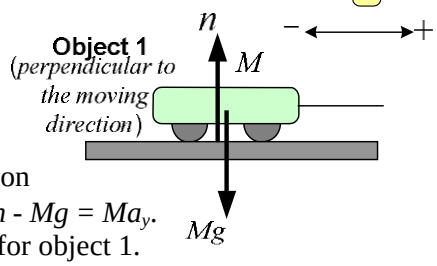
Introduction

Newton's laws consist of the "law of inertia", the "law of motion", and the "law of action and reaction." The first law ("inertia") says that an object's velocity will not change unless that object experiences acceleration by means of an external force. Think about a large box sitting on the floor or a moving car with no brakes, or air friction. The second law ("motion") goes on to say that any change in the object's velocity is inversely proportional to its mass and directly proportional to the force applied to it, and in the same direction as that force. Think about the force needed to get the box moving or to stop the car. The third law states that for every action on an object, there is an equal and opposite reaction, usually from within that object. Think about the force that the box puts on your hands as you attempt to move it or about the forces involved when two objects collide. The first two laws are governed by the vector equation $\boldsymbol{\Sigma F = ma}$ and deal with objects that experience external forces, with $a = 0$ in the case of the first law. The third law includes internal forces and the role they play in interactions. The SI unit of force is a Newton, N; the dimensions of force are $[M][L][T^{-2}]$, with SI units $^{kg*m}/s^2$.

For this lab, Atwood's machine is used to verify Newton's laws. The general definition of Atwood's machine is a uniformly accelerated motion of two objects connected by a string suspended over a pulley as shown to the right.

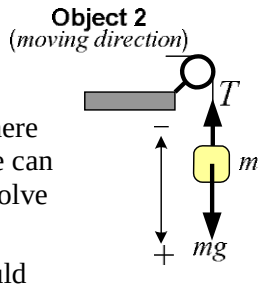
According to the "law of inertia," object 1 (cart with mass M) will remain still unless acted on by a force. But since there is a gravitational force applied to the cart via the pulley and the tension T in the string, it moves according to the "law of motion" as $\boldsymbol{\Sigma F = ma}$, where $\boldsymbol{F}$, $\boldsymbol{a}$ are vectors.





As shown in the two figures for object 1 to the right, the sum of the forces in the x-direction (direction of motion) is $\Sigma F_x = +T = Ma_x$; that for the forces in the y-direction is $\Sigma F_y = +n - Mg = Ma_y$. So, $T = Ma_x$; but since the cart does not move up or down, $a_y = 0$, which implies $n = Mg$ for object 1.

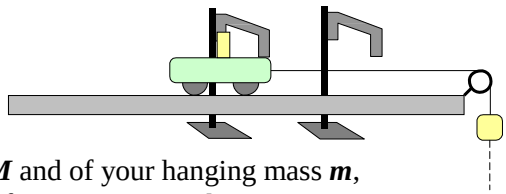
For object 2 (weight with mass m), the net force is the gravitational force mg, with the y-direction taken as the direction of gravity's pull on the weight, minus the tension in the string; then $\Sigma F_y = +mg - T = ma_y$. Notice here that $a_x = 0$ for object 2 since the weight only moves in the y-direction.



Now, since the "law of action and reaction" applies to where the string meets the cart as well as to where the string meets the weight, we can know that the tension in the string is the same for both objects; we can also say that a_x for the cart equals a_y for the weight, which we simply will call a. Thus, we can now solve for T in each case, and then set the results equal to find that $a = {}^{(mg)}/_{(M+m)}$ for this simple case.

Also notice that when the weight hits the floor and causes the string to stop pulling on the cart, it should continue to move with a constant velocity; this behavior is also explained by the "law of inertia" above.

1. *Acceleration along a Level Plane*



Procedure:

1) Use a balance to accurately measure the mass of your cart $\boldsymbol{M}$ and of your hanging mass $\boldsymbol{m}$, and then record your results below using correct significant figures, units, and uncertainty.

$\boldsymbol{M} \pm \Delta\boldsymbol{M}$ = _____ ± _____ ( ) $\boldsymbol{m} \pm \Delta\boldsymbol{m}$ = _____ ± _____ ( )

2) Setup the experiment as shown in the diagram above; use the bubble-level to ensure that the track is level by adjusting the track feet until both bubbles are centered. Verify that both photo gates hit the same location on the cart flag by ensuring both gates are set to the same height. The free body diagram for this setup is shown below.

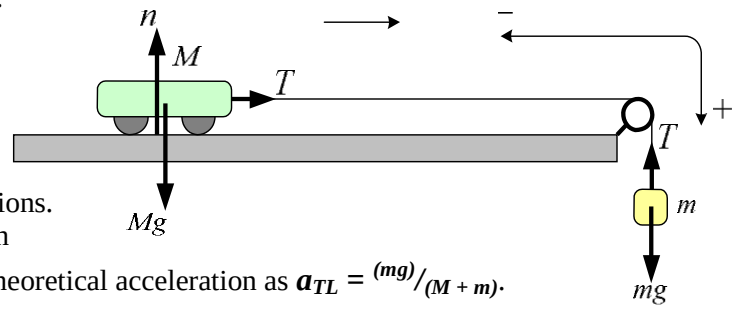
This gives the following force equations for each object as:

$\Sigma F_{Mx} = +T = Ma_{Mx}$ $\Sigma F_{My} = n - Mg = 0$

for the forces on the cart along the x and y directions, then

$\Sigma F_{mx} = ma_{mx} = 0$ $\Sigma F_{my} = mg - T = ma_{my}$

for the forces on the hanging mass along the x and y directions. Since the tension in the string is the same at both ends, then



$a_{Mx} = a_{my} \equiv a_{TL}$ and $T = Ma_{Mx} = mg - ma_{my}$ gives the theoretical acceleration as $a_{TL} = {}^{(mg)}/_{(M+m)}$.

Calculate values for a_{TL} and Δa_{TL}, where g = 9.807 $^{m}/_{s^2}$, and then properly record your results below.

$a_{TL} \pm \Delta a_{TL}$ = _____ ± _____ ( ) $d \pm \Delta d$ = _____ ± _____ ( )

3) Use a meter stick to measure the distance between the photo gates $\boldsymbol{d}$ and record your results above using correct significant figures, units, and uncertainty. Be sure that $\boldsymbol{d}$ is less than the initial height $\boldsymbol{h}$ of the hanging mass from the floor. This will ensure that the cart is uniformly accelerated throughout the entire distance $\boldsymbol{d}$.

4) Open DataStudio, click on "Create Experiment," and select photo gates for digital channels 1 and 2. Then open a "Table" and select "Time Between Any Gates." Recall that when measuring the acceleration due to gravity in part 3 of the "Kinematics" lab, the initial velocity v_i needed to equal zero in order to use the equation for acceleration $a_{EL} = {}^{2d}/_{t^2}$. That is also true here, so be careful to have the cart's flag as close to the photo gate as possible when you release it for each data run; this will ensure the validity of using $a_{EL} = {}^{2d}/_{t^2}$ for the cart here.

5) Ensuring that the initial velocity is zero for each run, use DataStudio to measure the time it takes for the cart to travel the distance $\boldsymbol{d}$ along the level surface, then record your measurements in the table to the right.

6) Calculate the acceleration for each run using the values measured for $\boldsymbol{t}$ in the table and $\boldsymbol{d}$ from above and record your results in the table to the right.
Note: Remember to square $\boldsymbol{t}$ when calculating a_{EL} here.

7) Click on "Experiment," select "New Empty Data Table," and enter your calculated values for a_{EL} into the "X" column of the new data table.

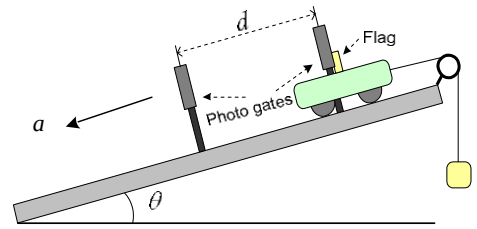
8) Select "mean" and "standard deviation" from the "Σ" drop-down at the top of the table, verify that values for mean and standard deviation appear on the table, and record these values with units in the space below. Do not print this table yet, we will use the "Y" column in part 2.

Travel time, t (photo gates)	Acceleration, $a_{EL} = (2d) \div t^2$

$a_{EL} \pm \Delta a_{EL}$ = _____ ± _____ ( )

Question: List all 4 sources of friction in this experiment below. Which of your values for $\boldsymbol{a}$ above is higher, a_{TL} or a_{EL}? Does this make sense in terms of the frictional forces present in this experiment? Briefly justify your answer below.

2. *Acceleration along an Inclined Plane (Lab Report)*



Procedure:

1) Setup the experiment as shown to the right. Use the rods mounted on the table to support the track so that it is raised and hangs off the end of the table. Use a weight that is small enough to allow the cart to roll down the track.
2) Use the balance to measure $\boldsymbol{m}$ and record your results using correct significant figures, units, and uncertainty to the right. $\boldsymbol{m} \pm \Delta\boldsymbol{m}$ = _____ ± _____ ( )

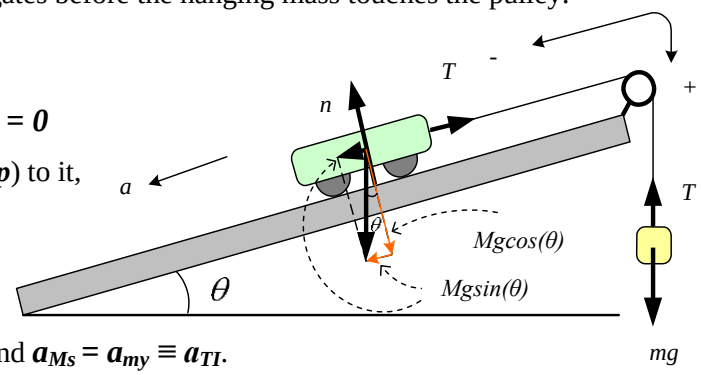
   Note that $\boldsymbol{M} \pm \Delta\boldsymbol{M}$ and $\boldsymbol{d} \pm \Delta\boldsymbol{d}$ should still be the same as in part 1 above; *verify* that they are. Be sure that you have enough string so that the cart can travel through both photo gates before the hanging mass touches the pulley.
3) The free body diagram for this setup is shown to the right. This gives the following force equations for each object as:

   $\boldsymbol{\Sigma F_{Ms} = T - Mg\sin(\theta) = Ma_{Ms}}$; $\boldsymbol{\Sigma F_{Mp} = n - Mg\cos(\theta) = 0}$

   for forces on the cart *along the slope* (**s**) and *perpendicular* (**p**) to it,

   $\boldsymbol{\Sigma F_{mx} = ma_{mx} = 0}$; $\boldsymbol{\Sigma F_{my} = mg - T = ma_{my}}$

   for forces on the hanging mass in the x and y directions. Since the tension in the string is the same at both ends,



   the following is true $\boldsymbol{T = mg - ma_{my} = Mg\sin(\theta) + Ma_{Ms}}$ and $\boldsymbol{a_{Ms} = a_{my} \equiv a_{TI}}$.

   As a result, the theoretical acceleration down the incline is given by $\boldsymbol{a_{TI}} = {}^{-g(M\sin(\theta) - m)}/_{(M + m)}$,

   where the minus sign shows that the cart moves down the incline and as before $\boldsymbol{g}$ = 9.807 $^{m}/_{s^2}$.
   Calculate values for $\boldsymbol{a_{TI}}$ and $\Delta\boldsymbol{a_{TI}}$, then properly record your results below.

   Note: use $\sin(1°) \approx 0.02$ for your uncertainty in $\sin(\theta)$. $\boldsymbol{a_{TI}} \pm \Delta\boldsymbol{a_{TI}}$ = _____ ± _____ ( )
4) Use the same DataStudio setup as in part 1 above to measure the time it now takes the cart to travel the distance $\boldsymbol{d}$ down the incline, and then calculate the values for $\boldsymbol{a_{EI}}$ as before; record your results in the table below.
5) Enter your calculated values for $\boldsymbol{a_{EI}}$ into the "Y" column of the data table from part 1 above.
6) Record your average and standard deviation values for $\boldsymbol{a_{EI}}$ in the space below; print the completed table now.

   $\boldsymbol{a_{EI}} \pm \Delta\boldsymbol{a_{EI}}$ = _____ ± _____ ( )

Travel time, $\boldsymbol{t}$ (photo gates)	Acceleration, $\boldsymbol{a_{EI} = (2d) \div t^2}$

Questions:

1) Which of your values for $\boldsymbol{a}$ above is higher, $\boldsymbol{a_{TI}}$ or $\boldsymbol{a_{EI}}$? Does this make sense in terms of the frictional forces present in this experiment? Justify your answer below.
2) Calculate the difference in your values for $\boldsymbol{a_T}$ and $\boldsymbol{a_E}$ as well as the sum of $\Delta\boldsymbol{a_T}$ and $\Delta\boldsymbol{a_E}$, and properly record below.

   $\boldsymbol{a_T} - \boldsymbol{a_E}$ = _____ ( ) $\Delta\boldsymbol{a_T} + \Delta\boldsymbol{a_E}$ = _____ ( )
3) Can your results for the case of the inclined plane be considered valid? Why or why not?