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PHYS 231 Lab Exercise: Newton's Second Law of Motion

<u>Objective:</u> As you are probably aware from everyday experience, heavier objects require a greater force to move around than lighter ones. Isaac Newton quantified observations like this one into what is probably the most useful expression in all of physics: $\boldsymbol{F} = M\boldsymbol{a}$, otherwise known as *Newton's 2nd Law of Motion*. Here, $\boldsymbol{F}$ is the net external force acting on mass M, and $\boldsymbol{a}$ is the resulting acceleration.

The *primary objective for this lab is* to test the conjecture that Newton's 2nd Law of Motion does apply to actual laboratory measured motions.

<u>Introduction</u> The interaction between various objects is responsible for a whole variety of phenomena in our universe. If no interactions existed, our universe would consist of a bunch of objects engaged in *motion at constant velocity* in accordance to Newton's first law. We couldn't even perceive this universe, because our perceptions are due to interactions with the external environment (*e.g.* – our vision is due to our interaction with light). In fact, we could not exist without the interactions that bind our constituent cells together!

For this reason, *Force* is a critical physical concept. While we can't test every possible situation in which forces act, we do know that Newton's second law was based on Newton's observations that that the acceleration of an object experiences is directly proportional to the applied force. In equation form this is

$$F = Ma \tag{1}$$

where F is applied force, a is its acceleration, and M is the coefficient relating force and acceleration. M is a property of the object being accelerated called *mass* and is directly proportional to how much force is needed to achieve a given acceleration. In other words, *more massive objects require greater forces to achieve the same acceleration as less massive objects.* We will be testing the proportionality of acceleration to force in today's lab exercise.

From equation (1), it should be clear that the units of Force are mass units (kg) times acceleration units (m/s^2) or kg•m/s^2. This unit is called a *Newton* where
1 N = 1 kg•m/s^2.

<u>Apparatus:</u> Balance, Air-Track, minimum of three gliders, clips, spark counter, ruler, wax-coated tape.

<u>Procedure:</u> Each air track is equipped with gliders, string, wax tape, and clip assemblies. Since the glider on the air track rests on a thin film of air, it moves almost completely without friction.

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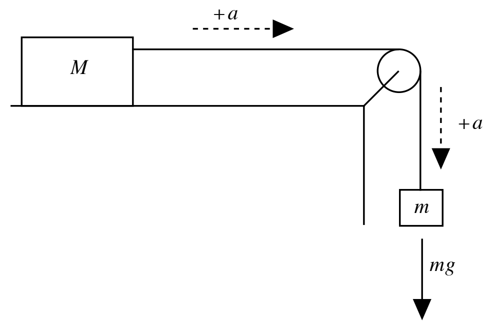
A glider is placed on the air track with a string and hanging weight attached. The hanging mass m has a weight, which produces a force $F=mg$ on the glider. Both the glider with mass M and the hanging mass m are accelerated, therefore this force,



$$F = mg = (M+m)a = M_{tot}a \quad (2)$$

where a is the acceleration of the glider (and the hanging mass). So experimentally your goal is to measure the acceleration of the glider, a, and confirm that it matches the prediction of Newton's 2nd Law that:

$$a = (m/M_{tot})g \quad (3)$$

The air tracks are set up to initiate sparks at regular intervals (10 sparks per second) that will deposit identifiable marks on the wax tape stretched alongside the length of the track (just like the free-fall lab). If you prepare a glider-string-clip as in the figure, and release from rest, it will begin to move and provide opportunity to record position versus time onto the tape. From this we can determine the observed acceleration and compare it to the prediction from (3).

Part I: Acceleration as a function of Force

You will carry out your experiment by accelerating a constant mass with varying forces. We do this by accelerating the glider and 4 clips using gravity. The clips hanging from the string will provide the gravitational force.

By moving a clip from the glider to the hanging string, we will not change the total mass being accelerated, but we will change the hanging mass, and therefore the hanging weight. It is this weight that accelerates the mass, so by moving clips **we are varying the accelerating force (the weight of the clips) without varying the total mass being accelerated**.

a) Stretch out a fresh piece of wax tape along the air track and clip it down at the ends with metal clips. **Measure and record the mass of the glider. Then record the mass of the four clips all-together. Assume the mass of each clip is 1/4 this total mass.**

   What is the value of M_{total}, the sum of the masses of the glider and all 4 clips (the mass you will be accelerating)?

   Record the total mass ________________________ (include units)

b) Connect one end of the string to the glider; drape the other end over the pulley allowing it to hang. Attach one clip to the end of the string that is hanging below the pulley and attach three clips on the glider.

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c) Introduce air into the track by opening the valve and then release the glider. Recall that the glider now rests on a thin film of air, it moves almost completely without friction.

After the glider has begun to move, press down and hold the spark generator until the glider has moved completely to the other end of the track. **Turn off the sparker when the hanging mass hits the ground.**

BIG SAFETY TIP: Do not hold the glider in place by hand or touch the glider while the spark generator is on…you will likely get a nasty electrical shock if you do this. Have the same person release the glider as is pushing the spark switch.

Indicate on the wax tape how many clips are hanging over the pulley and record that number in the first column of a table (in Excel).

d) Repeat the last step, each time moving an additional clip from the glider to the hanging string. Make runs with 1, 2, 3, and 4 clips hanging off the string.

Now, we would like to compare the accelerating force (*mg*) to the observed average acceleration (a_{av}) to see if this is a linear relationship (as predicted by Newton's 2^{nd} Law)

e) For each of the four runs, *calculate the observed average acceleration using the method outlined in the "Data Analysis Hints" section at the end of this lab and record those values in Excel.*

f) Compute the applied force, which is the weight of the hanging masses ($W = mg$) on the glider for each one of the runs and *record these values in a new column in Excel*.

g) Using *Excel*, plot the applied force versus the observed average acceleration. Find the slope of this line using *Excel*.

Slope of force vs. observed acceleration: ____________

h) What are the units of this slope? ___________

i) Compare this slope to the total mass you are accelerating (from part a). How does it compare?

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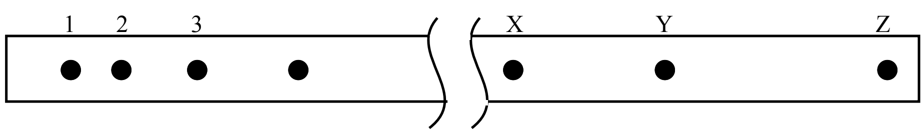
Part II: Analysis of Results

Answer the following questions:

a) How could you check experimentally that glider acceleration is constant during the motion and does not depend, for example, on the distance the glider moved through?
b) If you add some weight to (1) the hanging weight, and (2) the glider, how would the acceleration change in each case.
c) If you increase the hanging mass by 3 times and decrease the mass of the glider by 4 times, how will the acceleration change (*i.e.* How many times bigger or smaller will the acceleration be?)?
d) For your specific measurement of the acceleration, make a prediction of what the glider velocity and displacement would be if the glider were moving with this acceleration for 3 seconds.
e) It follows from Newton's 2^{nd} Law that acceleration is inversely proportional to the mass of an accelerating object, while keeping the applied force constant (*i.e.* $a \propto 1/M$ if F constant). How could you test this with the equipment available to you in this lab exercise?

Data Analysis Hint: Estimating Average Acceleration

Given that we have multiple datasets here (as opposed to the one in the free fall lab), we need a more efficient way of estimating acceleration than we previously used.



Consider the beginning of a particular wax tape and call the first three points 1, 2, and 3 (See the figure above). The velocity at point 2 is approximately the distance between points 1 and 3 divided by the time elapsed (1/5 second). Next, go to the far end of the tape and identify three consecutive dots which we shall here call X, Y, Z (**make sure these points occur before the weight hit the floor!).** Once again, the approximate velocity at point Y is the distance between X and Z divided by the time of 1/5 second. Finally, an estimate of the average acceleration is

$$a_{av} = \frac{v_Y - v_2}{t} \qquad (2)$$

where t is the time elapsed between points 2 and Y. You'll have to count the number of 1/10 second intervals between 2 and Y to get this number, but then you will have an estimate for the average acceleration over that elapsed time.

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DATA SHEET

(You may record the data in an *Excel* spreadsheet if you prefer, but please record the same data)

Spark frequency: ___________________________

Part I: *Acceleration as a Function of Applied Force.*

$a \propto F$ M is constant

Mass of glider, M_{glider}:__________________

Mass of 4 clips: __________________ ➔ Mass of one clip: __________________

Total mass of system, M: __________________

Number of clips hanging	Force, F	V_i	V_f	Calculated Acceleration	Expected Acceleration

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