PHY110/138 Laboratory

Module A/B: Acceleration and Forces

October 9 – November 5, 2007

[Based on materials being planned for the *U of T Physics Practicals*, to be launched in Fall 2008]
Last revision: Oct. 5, 2007 by JJBH

Purpose

To investigate the nature of acceleration, forces and Newton's Laws.

Equipment List

Item	Qty	Item	Qty
2.2 meter Track, Pasco ME-9453	1	1" cube of wood, homemade	1
Collision Cart, Pasco ME-9454	1	Bubble Level	1
PASCO 1.0 N Metric Spring Scale, SE-8714	1	PASCO Fan Accessory with guard, and 2 aluminum dummies shaped like AA batteries	1
OHAUS 20 N Dial Spring Scale	1	AA batteries	4
#24 Rubber Bands (4" long, 1/8" wide, 1/32" thick)	4	PASCO 500 g cart mass	1
Set of risers, homemade • 4 x 1.000 cm thick blocks, ~ 3" x 6" • 4 x 0.500 cm thick blocks, ~ 3" x 6" • 4 x 0.100 cm thick blocks, ~ 3" x 6"	1	Digital stopwatch Vernier Caliper Small screwdriver for prying out batteries	1 1 1
Deck of cards, thickness written on the box	1	Digital scale	1/room

Setup Notes:

The feet brackets should support the Track at about 60 cm and 170 cm as measured on the Track's scale. They should be mounted so their thumbscrews are on the same side of the Track as the scale.

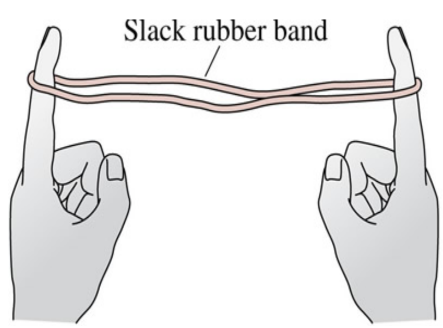
The Track should be set up with the end with the largest reading on the scale near the edge of the table. The Track should be leveled and the feet locked. End brackets should be on both ends so the cart cannot easily roll off the end.

Activity 1: What does "force" feel like?

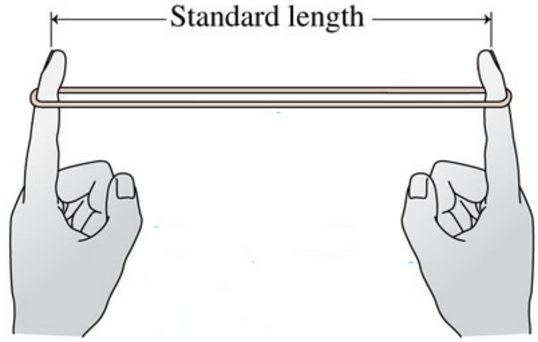
[based on Practical 2.12 and 2.13]

In this Activity you will use a *Spring Scale*. This device measures forces exerted on it.

Pick out one of the Number 24 rubber bands as your standard rubber band. You may want to identify it by marking it with a pen or pencil. Loop the rubber band loose around your fingers as shown. Slowly separate your hands until the rubber band is not slack.

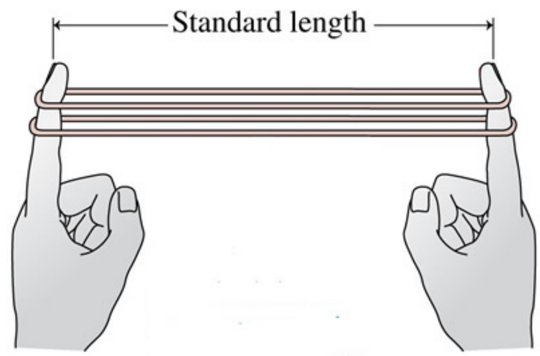


Now separate your hands by some further predetermined “standard” length that you choose. You can feel that the rubber band is exerting forces on both of your fingers. How do the magnitudes of these two forces compare?



Each member of your Team should do this simple little experiment.

A. When stretched by the standard length the rubber band is exerting a *standard force* on your fingers. Decide what name you wish to give to this standard force.
B. Now loop the rubber band around the hook on the *Spring Scale*. **Do not overstretch the spring scale by exceeding its maximum reading!** Stretch the rubber band by the standard length and determine the force in newtons corresponding to your standard force.
C. Now loop two rubber bands around your fingers and stretch them by your standard length. How does the force exerted on your fingers with two rubber bands compare to just one?
D. Repeat with three rubber bands.
E. Use the Spring Scale to check your feelings about the magnitudes of the forces.
F. Is there any difference between the forces exerted on the Spring Scale by a rubber band and an equal force exerted on it when you just hold the hook and pull? Explain.



Activity 2: Friction on a Rolling Cart

[based on Practical 2.10]

The next few Activities will involve a Track and Collision Cart. The Track should be leveled, but you should check to make sure.

1. Push the Cart and let it run up and down the Track a few times to warm up the bearings in its wheels.
2. Place the Cart near one end of the Track and give it a very gentle push. It should drift a few centimeters and stop. Give the Cart a very gentle push in the opposite direction: it should drift a few centimeters and stop. If the Cart has a tendency to stop and reverse its direction then the Track needs leveling.

The feet under the Track are adjustable by loosening the lock nut and rotating the feet. Be sure to tighten the lock nut when you have the Track level. The Instructors have a level, which may help. The level will be required if you suspect that the Track is not level along the axis perpendicular to its length.

Please do not adjust the positions where the feet are mounted on the Track.

Note that although the Carts have low friction, the fact that they do slow down and stop means the friction is not zero.

At this time, you will find it convenient to measure and record the distance between the feet. The mounts for the feet provide a convenient way to do this. Estimate the position of one of the mounts with the scale mounted on the Track and the corresponding position of the other mount.

You are provided with a set of blocks which will be placed under the feet tilt the Track. There are blocks that are 1.000 cm, 0.500 cm, and 0.100 cm thick. In addition, for one of the Activities you will need finer adjustments than these blocks provide. It turns out that good quality playing cards are carefully controlled in all their dimensions, and are typically 0.029 cm thick. You are provided a deck of playing cards with the card thickness written on the box.

Use the thin blocks to raise the side of the Track closest to the edge of the table a few millimeters.

A. Place the Cart on the Track near the end closest to the edge of the table and give it a very gentle push. Does it move at a constant speed down the track? If it is slowing down, raise the height a bit more. If it is speeding up, reduce the height. At what height does the Cart move at approximately constant speed? The playing cards are a good way to make small changes in the height.
B. When the Cart is moving at constant speed down the Track, sketch a Motion Diagram of its motion.
C. When the Cart is moving at constant speed down the Track, sketch a Free Body Diagram of all the forces acting on the Cart when it is about half-way down the Track.
D. How much can you vary the height of the track and not see any difference in the motion of the Cart? The playing cards are a good way to introduce small changes in the height.
E. Express your result from Part A as an angle. Include your result from Part D by adding a ± *error* term to the angle.
F. You are supplied a wooden block. Place the block in front of the Cart so the cart will push it down the Track. Now there will be more friction. Now what height must you raise the Track to have the Cart moving at approximately constant speed? At what angle is the track?
G. Sketch a Free Body Diagram of all the forces acting on the Cart for Part F.
H. If you could completely eliminate the friction of the Cart and Track, what height would the end of the Track be raised for the Cart to move at constant speed? What would be the angle of the track?
I. Is it ever possible to completely eliminate friction?
J. Remove the wooden block but keep the Track at the same angle as Part F. Give the Cart a gentle push. Draw a Motion Diagram of its motion down the Track.
K. Draw a Free Body Diagram of all the forces acting on the Cart in Part J when it is about half-way down the Track. Compare to your Free Body Diagram of Part C.

Activity 3: The relation of force and acceleration

[based on Practical 2.14]

In this Activity you will use a *Fan Accessory*. The fan accessory clamps to the collision cart and produces an approximately constant force upon it. **Avoid a runaway Cart falling off the Track!**

Level the Track. Warm up the bearings of the wheels of the Fan Cart by rolling it up and down the Track a few times.

A. Put 4 AA batteries in the Fan Accessory. Carefully clip the fan accessory to the top of the collision cart, avoiding putting too much pressure on the wheels of the cart. Turn it on, let it go from rest and measure time for it to travel a specific distance. Use $d=1/2\ at^2$ to compute a.
B. Sketch a motion diagram of the Cart.
C. Consider the Cart, motor, fan and the housing for the fan as the system under consideration. Sketch a Free Body Diagram of all the force acting on the system when the Cart was accelerating in Part A.
D. Use the Spring Scale to measure the net horizontal force acting on the system when it is not moving. Is this the force acting on the system when it is moving?
E. Repeat steps A-D with two batteries swapped out for aluminum dummies. This will halve the voltage provided to the fan motor, decreasing the fan speed and decreasing the force on the system. Put the real batteries back where the dummies were so that the mass of the system remains the same.
F. Sketch a graph of acceleration versus force, with the force on the horizontal axis. Be sure to include the origin on the graph. Is there a "free" third data point that you can include in your graph? Hint: what is the acceleration of the Fan Cart when the fan is off?
G. Sketch a straight line that "fits" the two data points. Should the line go through the origin? What is the slope of this line, and what are the units?
[Recall that 1 N = 1 kg m s^{-2}]. How much can you vary the slope of the line and still more-or-less "fit" the data? Express the slope as a best fit and an error.
H. The slope of the acceleration versus force graph should give a prediction for the mass of the system in kg. What is this mass? Friction was neglected in this calculation. If friction does exist in the system (as we know it must) would it make our predicted mass higher or lower than the true value? Measure the mass of the cart and fan accessory.

Activity 4: The relation of force, acceleration and mass

[based on Practical 2.15]

A key aspect of the scientific method is that often when a physical system has many variables we can keep all but two of the variables constant, and can investigate how those two variables relate to each other. In Activity 3 you varied the force applied to the Cart and saw how different forces cause different accelerations of the Cart. In this Activity you will apply the same constant force to the Cart but will vary its mass.

A. Replace the dummies with batteries. Add a 500 g mass to the cart. Measure acceleration.
B. Sketch a graph of acceleration versus total mass, with the mass on the horizontal axis. Include the acceleration and mass from Activity 3 Part A.
C. Sketch a graph of acceleration versus one over the mass, with one over the mass on the horizontal axis. Include the origin in the graph. Is this graph simpler than the one in Part B?
D. For the graph of Part C, draw a straight line that "fits" the data. Should the line go through the origin? Why?
E. Write down the relation between mass m and acceleration a including any necessary constants and their errors. If you can find a force, compare it to the force that you measured in Activity 3, Part D.