

# FORCES

## 1 Introduction

Intuitively, we can define force as any kind of a push or a pull on an object. Forces always involve the interaction between two objects. One object always exerts a force on another object. When you push a grocery cart or a stalled car, you are exerting a force on it. On the other hand, forces don't always give rise to motion. For example, you may push very hard on a heavy sofa and it may not move. A force has direction as well as magnitude, and is indeed a vector that follows the rules of vector addition.

What is the exact connection between force and motion? It lies in Isaac Newton's three laws of motion. They state:

1. Every body continues in its state unless a net force is acted upon it.
2. The acceleration of an object is directly proportional to the force acted upon it and is inversely proportional to its mass.
3. When one object exerts a force on another, that object receives an equal (but opposite) force exerted on it by the other object.

In today's lab, you will be investigating these three laws through three different experiments. We will be measuring velocity and force to verify Newton's laws of motion.

Consider two masses,  $M_A$  and  $M_B$ .  $M_A$  is on a table.  $M_B$  is hanging off the table by a string wrapped around a pulley and held by  $M_A$ . This is depicted in the figure below:



In the first part of this lab, you will be varying the hanging mass ( $M_B$ ) and measuring the force and acceleration of  $M_A$ .

## 2 Equipment

- air track,
- string,
- pulley,
- masses,
- sonar ranger,
- computer,
- air cart

## 3 Procedure

Read through the procedures and familiarize yourself with the equipment. This lab write-up will provide space for you to record and analyze your data.

1. Set up the system shown above using the equipment stated on the first page. Carefully level the airtrack. Adjust the flow of air so that friction on the track is negligible. In setting up this system, cut the string long enough so that  $M_B$  just barely misses the floor (don't let it hit the floor)
  2. Insert a flag into the top of the glider. Measure the total mass of the glider and flags as well as any additional masses you need.
  3. Assuming friction is negligible, draw a force diagram below showing all of the forces in the system.
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4. Using the force diagram above, analytically determine the acceleration of the masses as a function of  $M_A$ ,  $M_B$  and  $g$  (Check with the lab instructor that your answer is correct).
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5. If the system is frictionless, is it possible for  $M_B$  to accelerate at  $g$ ? \_\_\_\_\_
  6. If the system is frictionless and  $M_B > 0$ , is it possible for  $M_B$  to move at a constant velocity? \_\_\_\_\_

7. Assume that there is friction between  $M_A$  and the airtrack. Draw the force diagram showing all of the forces for the system.
  
8. Using the force diagram above, analytically determine the coefficient of friction as a function of  $M_A$ ,  $M_B$ ,  $g$  and  $a$ .
  
9. If there is friction, is it possible for  $M_B$  to accelerate at  $g$ ? \_\_\_\_\_
10. If there is friction, is it possible for  $M_B$  to move at a constant velocity? \_\_\_\_\_
  
11. Set up a sonar ranger at each end of the airtrack and setup the software to record the velocity of the glider for both sonar rangers.
12. Release the glider from rest and record the velocity as a function of time.
13. From the slope of the velocity vs time graph, determine the acceleration. Use the techniques developed in your previous labs to properly determine the uncertainty on the acceleration.

Mass of glider  $M_A$ : \_\_\_\_\_

Mass of  $M_B$ : \_\_\_\_\_

Run	acceleration
1	
2	
3	
4	
5	

Average acceleration: \_\_\_\_\_

14. Repeat with three other masses for  $M_B$ .

Mass of  $M_B$ : \_\_\_\_\_

Run	acceleration
1	
2	
3	
4	
5	

Average acceleration : \_\_\_\_\_

Mass of  $M_B$ : \_\_\_\_\_

Run	acceleration
1	
2	
3	
4	
5	

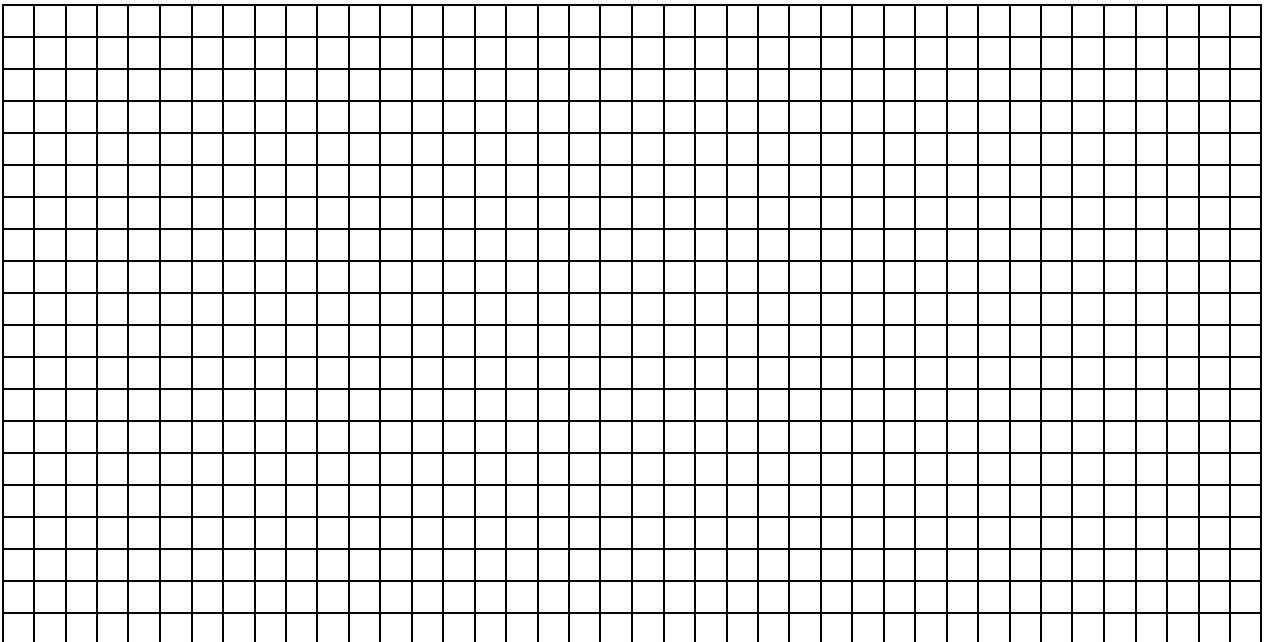
Average acceleration : \_\_\_\_\_

Mass of  $M_B$ : \_\_\_\_\_

Run	acceleration
1	
2	
3	
4	
5	

Average acceleration : \_\_\_\_\_

15. Make a graph of force vs. acceleration for  $M_A$  and find the slope. What should the slope of this graph represent? Does the slope value of the slope agree with your expectation? Explain.



16. Using your measured values and the equation you determined for the coefficient of friction in question 8, determine the coefficient of friction. Is it consistent with 0? Make sure you use correct statistical analysis to determine if the value is consistent with 0.

### 3 Frictional Forces

When two objects come in contact with each other forces will be acting between the surfaces. A frictional force which acts parallel to the surface prevents relative motion between the two surfaces. In this section of the lab, we will be investigating both static and kinetic friction.

#### Static Friction:

1. Set up the system as shown using a friction board and wood block  $M_A$ .



2. Measure the total mass of the wood block.  $M_A =$  \_\_\_\_\_
3. Normal force on wood block  $F_N =$  \_\_\_\_\_
4. Slowly begin to add mass to  $M_B$ . Since the objects are not accelerating, the force applied to  $M_A = M_B g$ .

5. Determine the coefficient of static friction,  $\mu_s$ , for each surface by measuring the amount of force required to just start the wood block moving. Note the coefficient of static friction is defined as the ratio of the maximum force required to move the object divided by the normal force ( $\mu_s = F_{\max}/F_N$ ). Note that the boards may have small imperfections, the boards may not be perfectly flat etc. So it is important to place the block at different positions on the board to find the force required to make the block move. If you find that you get slightly different results, this will be a systematic uncertainty in your measurement of the static friction. Make multiple measurements to get a good measure of the static friction for each case and report the average force required (with its uncertainty)

Surface	Force Trial 1	$\mu_s$
Wood		
Vinyl		
Sandpaper		
Cardboard		

6. After measuring the force for the wood block alone, add masses to the top of the block to increase the normal force. Repeat the above measurement. Add mass to the wood block again and repeat a third time.

Mass of wood block + masses : \_\_\_\_\_

Surface	Force Trial 2	$\mu_s$
Wood		
Vinyl		
Sandpaper		
Cardboard		

Mass of wood block + masses : \_\_\_\_\_

Surface	Force Trial 3	$\mu_s$
Wood		
Vinyl		
Sandpaper		
Cardboard		

Question: Do you expect the value of  $\mu_s$  to depend on the mass of the block? Does it make sense to average the values of  $\mu_s$  for each trial? If it does make sense, average your values to get a final measurement and uncertainty for  $\mu_s$

Surface	$\mu_s$
Wood	
Vinyl	
Sandpaper	
Cardboard	

Question: Since there is a minimum mass that can be added to  $M_B$  (the smallest mass you have), you can only find the minimum force required to move the block to this uncertainty. Does the effect of only having a minimum mass change as you add more mass to the wood block?

Question: Once the wood block begins to move, will it continue to move at a constant velocity or will it accelerate? Explain.



## Kinetic friction:

Once an object begins to move, static friction no longer applies and kinetic friction occurs. In this section we will investigate

1. Set up the apparatus as in the static friction case.
2. Slowly add mass to  $M_B$ .
3. Give the wood block a tap to get it moving. This is necessary to overcome static friction.
4. Continue to add mass to  $M_B$ , until the wood block moves at a constant velocity after giving the wood block a tap.
5. Calculate the coefficient of kinetic friction ( $\mu_K$ ) for each surface.
6. Add masses and repeat as for static friction.

Mass of wood block + masses : \_\_\_\_\_

Surface	Force Trial 1	$\mu_K$
Wood		
Vinyl		
Sandpaper		
Cardboard		

Mass of wood block + masses : \_\_\_\_\_

Surface	Force Trial 2	$\mu_K$
Wood		
Vinyl		
Sandpaper		
Cardboard		

Mass of wood block + masses : \_\_\_\_\_

Surface	Force Trial 3	$\mu_k$
Wood		
Vinyl		
Sandpaper		
Cardboard		

Average values of  $\mu_k$

Surface	$\mu_k$
Wood	
Vinyl	
Sandpaper	
Cardboard	

Question. Before the wood block begins to move, are there any forces acting on the wood block? Name any forces acting on the block.

Question: Before the wood block begins to move, is there a net force acting on the wood block?

Question: If there is a net force acting on the block, can the wood block move at a constant velocity? Explain.

Question: Which is larger, the coefficient of kinetic friction or the coefficient of static friction. Is this expected?