Physics 123 Lab 5:
Newton's 3rd Law and the Friction Force

Physics 123: Electricity and Magnetism

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Introduction and Overview

In this lab you will continue the investigations of force that you began last week. You will use a force sensor to explore the forces that occur when two objects interact with each other. Then you will apply the ideas you have developed about forces to construct and apply a model for static friction.

Learning Targets

After completing this lab, you should be able to:

1. Explain and apply Newton's Third Law.
2. Determine the existence and direction of a static friction force acting on an object based on knowledge of the other forces acting on that object.
3. Distinguish the actual static friction force acting at a surface from the *maximum* possible static friction force (*i.e.*, upper limit of static friction) that can be exerted at that surface.
4. Apply a mathematical model for the upper limit of static friction ($f_{max} = \mu N$) to relate the maximum possible static friction force in a given system to the characteristics of the system.
5. Determine the coefficient of static friction experimentally.

Equipment:

- Motion sensor
- Computer and interface box
- One low friction cart
- One friction cart
- Track
- Force sensors (2) with spring bumpers
- Rectangular metal mass bars
- Cylindrical weight set
- Friction block
- Colored pencils, string and scissors

Preview of the Synthesis Challenge

For this week's challenge, you will be asked to design and carry out two independent experimental measurements of the coefficient of static friction of your own shoe!

Activity I: Forces and interactions

This activity focuses on Learning Target 1. You will use a pair of sensors to investigate the forces between two objects that interact with one another. To prepare, complete the following steps:

- Firmly secure each force sensor to its own low friction cart (use a small screwdriver).
- Remove the hooks from both sensors and replace them with identical spring bumpers. (You may have "floppy" and stiffer spring bumpers; it is best to start with the floppy bumpers.)
- Finally, place one metal mass bar on each of the carts.

A. Arrange the carts such that the sensors are pointed toward one another. Start data collection, and launch the carts toward each other with identical, small speeds.

(***Note***: It is useful to set up the sensors so that the same sign denotes forces exerted in the same physical direction in space. The premade templates are set to reverse the sign on one of the sensors.)

Sketch the resulting graphs on the axes at right.

B. As you have seen, the force graphs are symmetric. At each instant during the collision, the force exerted on the second cart by the first cart was equal in magnitude but opposite in direction to the force exerted on the first cart by the second.

The two forces you have measured are referred to as *interaction forces*. Your goal below is to explore the range of conditions over which the interaction forces are of equal magnitude.

Design and conduct experiments in order to explore the questions below. In each case, briefly describe your experiment and the results.

- Is the equality preserved when the masses of the carts are no longer equal?

- Is the equality preserved when only one of the carts is initially moving?

- Is the equality preserved if the springs are *not* equivalent, but one is floppy and the other stiff?

- Consider this scenario: A hand pushes one of the carts, which in turn pushes the second cart. The carts move together and continuously speed up as they traverse the track. The first cart has extra mass bars and the second does not. Do you think the force sensor readings will be equal and opposite?

- What other variables might affect the relative magnitudes of the interaction forces? Test any plausible variables that you can think of.

C. *Summarizing question:* Under what conditions are a pair of interaction forces equal in magnitude and opposite in direction?

Newton's Third Law states that if one object exerts a force on a second object, then the second object exerts a force of equal magnitude in the opposite direction on the first. The two forces that Newton's Third Law describes are sometimes referred to as *an interaction pair* or *a Newton's Third Law pair*. Note that Newton's Third Law is quite general: it applies to *any* pair of objects that are interacting with one another. The objects could be at rest or moving, the same size or different sizes, purple or white, *etc.*

D. Newton's Third law is, traditionally, a difficult topic for students first learning physics. Consider the following discussion between Devon and his partners about the experiments you have just conducted:

Devon: *"According to these results, the forces that two objects exert on each other are always the same magnitude, regardless of which object is bigger or which is moving faster."*

Victor: *"I agree that's what the data seems to be saying, but it doesn't make sense to me. During a collision, a bigger object ought to exert more force on a smaller object than the smaller exerts on the bigger."*

Kate: *" 'Bigger means more' does make intuitive sense. If a large truck and a small car have a collision, the truck has a bigger effect on the car than the car does on the truck."*

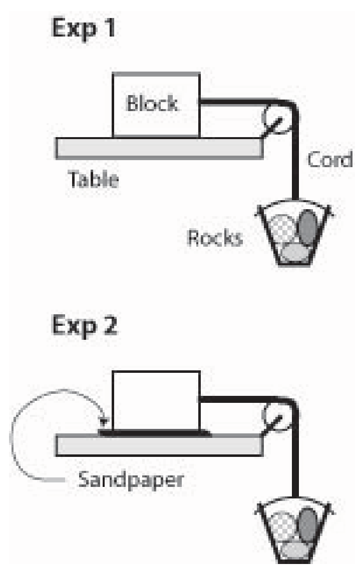
Devon: *"Maybe there is a way to make sense of 'bigger means more' with the results of our experiments."*

Together with your partners, discuss the dialogue above. Help Devon, Victor, and Kate sort out their ideas about forces and interactions. Is there a resolution to the conflict they perceive between the intuitive idea "bigger means more" and the results of their experiments on Newton's third law?

Activity II: Static friction and the "breaking point"

This activity addresses Learning Targets 1, 2, and 3.

Friction forces can be categorized into two types: *static* friction and *kinetic* (or *sliding*) friction. A static friction force is one in which the two interacting objects are not moving relative to one another.



A. A student conducts experiments with a block connected to a bucket of rocks by means of a cord and pulley. In Exp 2, sandpaper is glued onto the table; in Exp 1, there is no sandpaper. The system remains at rest in each case.

   1. Is the magnitude of the friction force exerted on the block in Exp 2 *greater than, less than,* or *equal to* that in Exp 1? Explain.

2. Sketch a free-body diagram (FBD) for the block in Exp 1 in the box below.

> ***Drawing free-body diagrams.***
>
> The block's free-body diagram should show all of the forces exerted ***on*** the block, but not forces exerted ***by*** the block. For each force that you draw, think about *the type of force, the object on which the force is exerted,* and *the object exerting the force.*
>
> To express this information concisely, use a notation in which the first letter indicates the *type* of force ("W" for a weight force, "N" for a normal force, *etc.*), the first subscript indicates the object ***exerting*** the force ("C" for cord, "E" for Earth, *etc*.), and the second subscript indicates the object ***on which*** the force is exerted ("B" for block). Thus W_{EB} represents the weight force exerted by the Earth on the block.

Free body diagram for block in Exp 1

B. Label the forces on your FBD according to the above convention.

Your FBD should have two vertical forces: the weight force exerted by the Earth and the normal force exerted by the table. Do these two constitute a Newton's third law force pair? Explain.

Should two force vectors that represent a Newton's third law pair show up on the same FBD or on two different FBD's? Explain.

How many distinct subscript letters should show up on the two force vectors that constitute a third law pair? two? three? more than three? Explain.

C. Consider the gravitational force exerted on the block by the Earth. What is the third law pair that goes along with this force? What can you say about its magnitude?

D. Together with your partners, rank the magnitude of the horizontal forces on your free-body diagram. Explain your reasoning.

How, if at all, would the free-body diagram for the block be different in Exp 2?

E. Together with your partners, discuss your original comparison of the magnitudes of the friction forces in Experiments 1 and 2. Is your original answer consistent with your results from the rest of the activity? If not, how should your answer be modified?

In a given situation, the *direction* of the static friction force is opposite to the direction of the motion that would occur if friction were not present. In addition, there may be an upper limit to the *magnitude* that a static friction force can have. We will refer to the maximum possible magnitude of a static friction force as the *breaking point,* or f_{max}.

Activity III: A model for static friction

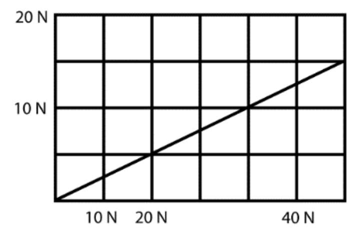
This activity focuses on Learning Targets 4 and 5.
Obtain a wooden friction block and place it felt side down on the metal track. Place two metal bars on the block. Attach a spring scale to the block with a light string, and pull horizontally with gradually increasing strength until the block starts to move.

A. Your goal is to measure the breaking point of static friction, f_{max}. There is uncertainty in this measurement, so perform a few trials to make sure the result is reproducible and to improve your estimate of the breaking point. When you are satisfied, record your result.

B. Now figure out a way to apply a steady, downward force of 5 N to the top of the block/bar system. Predict how this will affect the breaking point. Will the breaking point increase? If so, by 5 N? Discuss your ideas with your partners.

C. Do the experiment and check your prediction. Did the breaking point increasing by *about 5 N, more than 5 N,* or *less than 5 N?*

D. Another lab group uses a different block/track set up and collects data for several different strengths of the downward force. The graph at right shows the group's best fit line for **breaking point** (on the vertical axis) *vs* **magnitude of the normal force** (on the horizontal axis). (Note: "*Normal force*" refers to the normal force by the track on the block.)



Compute and interpret the slope of the graph. What specific information is this number telling you about the situation?

The slope that you computed above is referred to as the *coefficient of static friction.* This quantity is often represented by the Greek letter μ (mu). In the model for static friction, the coefficient depends on the "roughness" of the contact surface, but not on the surface area of contact.

E. Write an equation for the breaking point in terms of N_{TB}. This equation can be considered a mathematical model for the breaking point of static friction f_{max}.

The model for the static friction force is often written as $f_{static} \leq \mu N$. Describe the conditions under which the "≤" symbol in the relation above can be replaced with "=".

Activity IV: Reflection

Review your original prelab responses. Together with your partners, go over the questions and come to agreement on how to explain them. As you go, use colored pencils to annotate your prelab. Use green or blue to underline the parts of your reasoning that were productive, and red to underline parts that you now feel are problematic and need revising. Add comments to identify where and how your initial ideas were problematic. Focus not just on whether or not you had the correct answers, but also on the quality of your explanations. Discuss your reflections with your partners.

Before going on, check your thinking with an instructor.

Activity V: Synthesis challenge

Together with your partners, formulate and carry out two independent methods for determining the coefficient of static friction of your shoe.

Record notes, data, calculations, sketches, graphs, *etc.* that were important in your thinking process. As HW, you will write a mini-report describing your solution in enough detail so that another group could follow and repeat your experiment. To write this report, you may wish to refer back to your notes.