Chapter 2

Thrust and Friction

In the investigation of Forces and Newton's Laws, the concepts of Thrust and Friction appear time and time again. Thrust is a force which acts on an object (for example a airplane or boat) in reaction to a force being applied on something else (like the air or water). It is a consequence of Newton's Third Law. For example, in a motor boat, the propeller of the motor forces water backwards, thus forcing the boat forwards- the force on the boat forwards is in reaction to the force the propeller exerts on the water backwards. Friction is the force which results from the interaction of the surface of a moving object with another surface. The force of friction is always directly opposite to the velocity, and in some systems is a source of unwanted resistance to motion. However, in many cases, friction is highly desirable (imagine walking to class without friction).

Apparatus Cart track, Cart with fan, friction blocks, computer, data acquisition system (Logger Pro), weights, balance, stopwatch.

2.1 Prelab

1. A rocket is launched vertically from rest, it reaches an altitude of $5.2km$ after $16s$ of constant acceleration. What was the magnitude of the acceleration of the rocket? How many times larger than the acceleration due to gravity is this? Is this rocket safe for human passengers?

2. Give three examples of static friction.

3. Give three examples of kinetic friction.

4. Calculate the error in acceleration (equation 2.1) assuming v_o=0 m/s, $\Delta x \pm \delta x$ and $t \pm \delta t$.

2.2 Thrust

2.2.1 Introduction

In this lab activity you will study the acceleration of a cart when acted upon by a thrust force generated by a fan mounted onto the cart. Note that in contrast to the Linear Motion experiment, the track on which the cart moves will be horizontal, so the force of gravity will always be perfectly balanced by the Normal force. You will investigate the acceleration of the cart for forces of varying magnitude, carts of varying weights, and forces applied at various angles with respect to the direction of motion. Note that when the fan is turned on at a particular setting, it very quickly spins up to full speed and achieves a condition of providing a constant thrust (force).

2.2.2 Setup and Explore

In this exercise, you will have a chance to make qualitative observations regarding the motion of the cart, but first the track must be setup. The experimental setup is shown in figure 2.1.

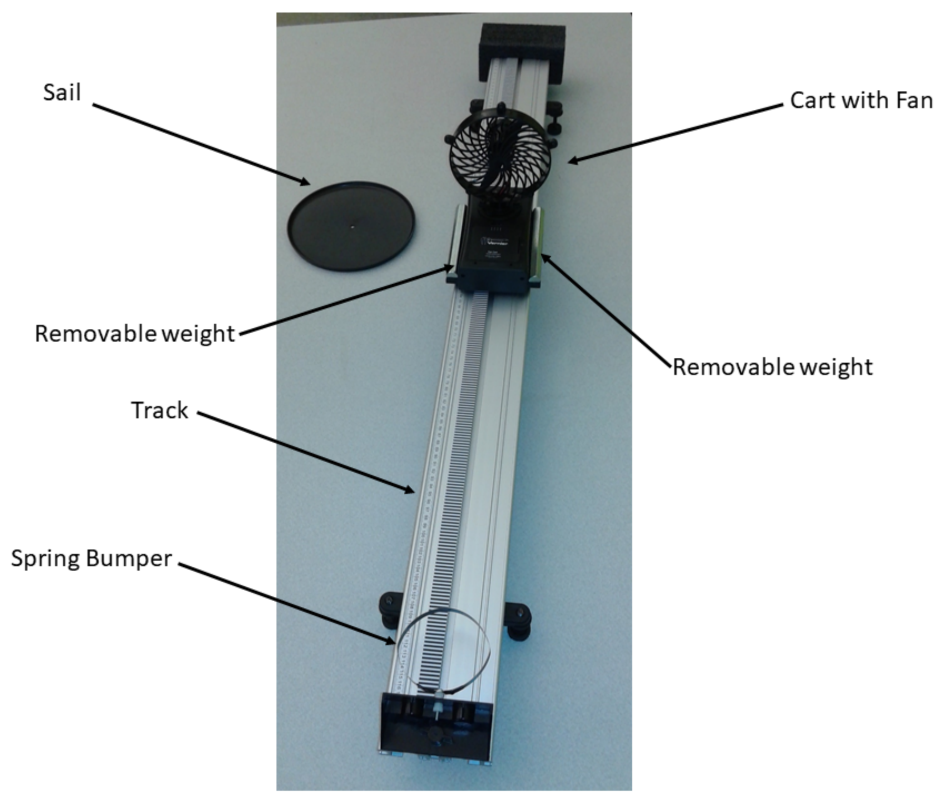


Figure 2.1: Experimental setup of Thrust experiment.

1. It is critical that the track is perfectly level so that the force of gravity can be perfectly balanced by the Normal force. To do this, use the digital level, and adjust the four support feet of the track.
2. Gently place the cart on the track, and ensure the wheels of the cart are properly in the grooves of the track. Notice the removable weights which can be placed along the sides of the cart.
3. **Draw** a free-body diagram of the cart with the fan turned off.
4. Turn on the fan to the lowest setting and observe the motion of the cart.
5. **Draw** a free-body diagram of the cart with the fan turned on. **Question:** Is this constant velocity? **Question:** Is this constant acceleration?
6. Observe and **comment** on the motion of the cart as a function of fan speed.
7. Observe and **comment** on the motion of the cart as a function of fan angle.
8. Observe and **comment** on the motion of the cart with and without the weights.

2.2.3 Quantify

In this exercise, we will investigate more closely the effect of the direction of the thrust (fan angle). To do this, we want to determine the acceleration of the cart. We could use a computer-based data-collection system like was used in the Linear Motion lab. Here, however, we will apply our physics knowledge to determine the acceleration. You have certainly seen a number of kinematics equations in your lectures which can be used to solve a large variety of motion problems. We will apply one such equation here.

$$\vec{x}(t) = \vec{v_0}t + \frac{1}{2}\vec{a}t^2 \tag{2.1}$$

To determine the acceleration $\vec{a}$ using equation 2.1, you should measure the time t it takes the cart, starting from rest ($\vec{v}(t=0) = \vec{v_0} = 0$), to travel to position $\vec{x}(t)$. The distance travelled is then $\Delta\vec{x} = \vec{x}(t) - \vec{x}_0$. When collecting data, hold the cart fixed at some location, turn on the fan, then start the timer as you release the cart. For this exercise, set the fan speed to 2, and include the weights on the cart.

Tasks:

1. Measure the time it takes for the cart to travel a given distance down the track for the various fan angles given in Table D.2 of Appendix D. Record your values in that table. **Note:** At each angle repeat the time measurement 3 times and find the mean and average deviation as described in Appendix A.
2. Calculate the acceleration of the cart using equation 2.1, and record the result in the table.
3. **Question:** From geometry, what is the equation for the component of Thrust in the direction of motion as a function of fan angle?

4. **Question:** What force balances the component of Thrust perpendicular to the track?
5. Plot your data points for Acceleration vs Fan Angle on the graph below the table.
6. **Question:** Does your data follow the expected trend?
7. **Question:** What assumption was made in order to use equation 2.1?

2.2.4 Explore Some More

If time permits, play around with mounting the sail on the back of the fan. Note that there are two possible mounting directions for the fan- one in which the slightly curved edge of the fan faces forward, and one where it faces backward.

1. Affix the sail to the fan so that the curved-edge of the sail faces forwards. **Draw** a free-body diagram for the cart/fan/sail object. **Comment** on the motion.
2. In which direction are the air molecules forced by the sail? Newton's Third Law tells the cart/fan/sail must therefore be forced in the opposite direction.

2.3 Friction

2.3.1 Introduction

Forces of friction are of immense importance because up to 1/3 of all energy produced in the world is "wasted" because of them. In this lab you will be investigating sliding and static, dry forces of friction, as opposed to fluid friction (viscous drag). The static force of friction f_s is given by the following inequality:

$$f_s \leq \mu_s N \tag{2.2}$$

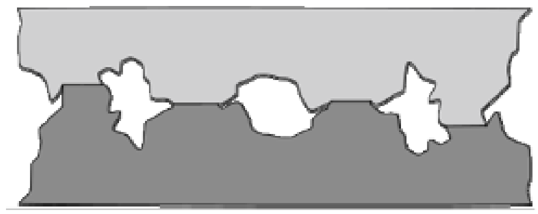
where μ_s is the coefficient of static friction and N is the normal force. (Here "normal" means that the force is perpendicular to the direction of f_s.) The inequality signifies that the static force of friction may have a range of values, from zero to a maximum value of $f_{s,max} = \mu_s N$.

The kinetic force of sliding friction f_k is given by the following equation:

$$f_k = \mu_k N \tag{2.3}$$

where μ_k is the coefficient of kinetic friction and N is the normal force (directed perpendicular to the direction of motion).

The kinetic force of sliding friction does not depend on the speed of the object, although at very low and very high speeds this may not be true. Static and kinetic forces of friction do not depend on the apparent surface area although they depend on the actual or real contact area between the two surfaces. The difference between the apparent and actual contact areas is explained in the figure below.



Surfaces, at a microscopic level, are very rough. Therefore, two surfaces are never in total contact. The object that slides is supported by the surface at the top of roughness irregularities, called asperities. These asperities deform until the weight of the object is fully supported. Approximately only 1 part in 10,000 of the apparent area is usually in contact, which is the reason why friction is effectively independent of the apparent area of contact. For very smooth surfaces the actual contact area may be a significant fraction of the apparent contact area and in this case friction is dependent on the size of the surface.

The actual contact area depends on the magnitude of the normal force. The larger the normal force the more the two surfaces push against each other, increasing the actual contact area and the force of friction. Because friction, from the microscopic point of view, occurs due to interactions between electrical charges, the larger the actual contact area between two surfaces, the larger the force of friction. The electrical interaction that causes friction is quite complex and it is still the current topic of research.

2.3.2 Measuring Static and Kinetic Coefficients of Friction

You've likely had the experience of pushing or pulling a heavy object on the floor- it is harder to get the object moving initially than it is to keep it moving. That is because the coefficient of static friction is greater than the coefficient of kinetic friction, meaning the static friction force is greater. In this experiment, we will apply a slowly increasing force to a stationary object, and measure the forces which oppose the motion.

2.3.3 Setup

The cart is connected by a string to the DC motor. A separate string is used to connect the force sensor to the friction block being pulled. Additional weights can be mounted on the friction block in order to increase the magnitude of the normal force. The force sensor is mounted on the cart and can be pulled either by hand or by a DC motor. You should try both ways but it is very likely that you will conclude that pulling the friction block by hand does not give as good results as using the motor. A variable power supply is used to control the speed of the motor. For voltages of about 3 V, the speed of the motor is very low, which allows collecting many experimental points during the transition of the block from being stationary to being in motion. The string connecting the cart to the motor is tied onto the shaft of the motor.

The force sensor is connected to the computer interface. As in previous labs, you will use the Logger Pro software to analyze the experimental data.

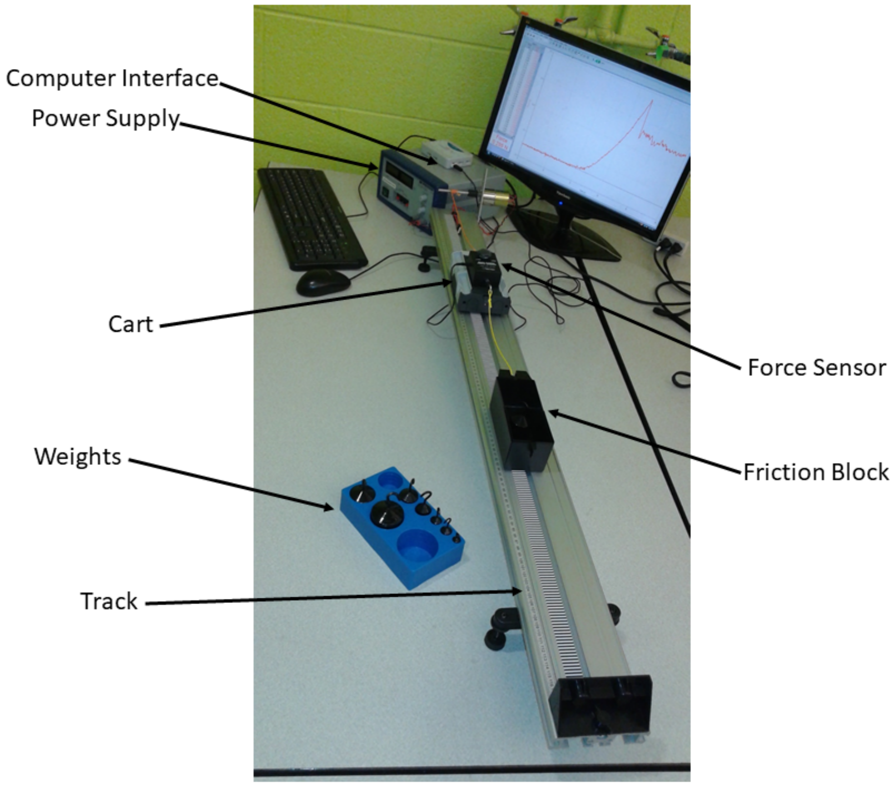


Figure 2.2: Experimental setup for measuring static and kinetic coefficients of friction.

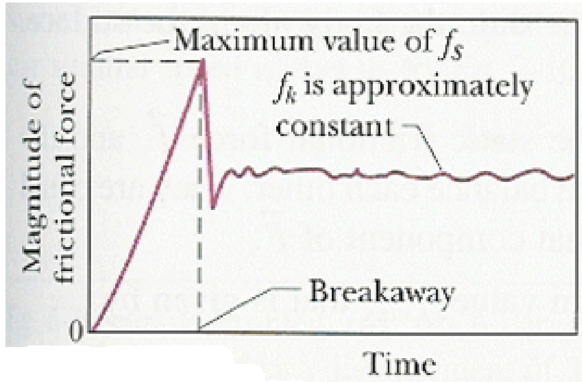
2.3.4 Procedure

- Start Logger Pro and then zero the force detector by clicking on the Zero icon in the toolbar. Both strings should not be under tension at this point.
- The duration of the data collection is 10 s. (If not already set to 10s, you can change it by clicking on the maximum value of time on the horizontal axis and typing new value or by clicking on the Data Collection icon in the toolbar and changing Duration to 10 s.
- Click on  to begin to acquire data just before you turn the motor on.

A typical dependence of the force as a function of time is shown below.

The maximum magnitude of the recorded force is equal to the maximum value of the static force of friction f_s, max.

Click on the Examine tool  in the tool bar and determine $f_{s,max}$ and then use the equation $f_s \leq \mu_s N$ to determine μ_s. The normal force is $N = (M_{block} + M_{added})g$, where M_{block} is the mass of the block and M_{added} is the additional mass placed on the block, and g



is the acceleration of gravity. $N = (M_{block} + M_{added})g$ only if the string connecting the force sensor to the block is horizontal. Measure both masses using the electronic balance.

Determine the kinetic force of friction f_k using the approximately horizontal part after the breakaway point of the graph. Small fluctuation of the force should be averaged out by using the Statistics tool (STAT icon in the toolbar) and finding the mean value of f_k. Once the icon is initiated the two small black brackets activated can be moved to highlight only the region of interest after the breakaway point. Use the equation $f_k = \mu_k N$ to determine μ_k. As for the static friction, $N = (M_{block} + M_{added})g$.

- Repeat for the same material, with 3 different masses. Record your data in Table D.3 of Appendix D.
- Repeat for a block which has a different material on its base, for 1 value of mass. Record your data in Table D.4 of Appendix D.
- **Question:** Is the force of kinetic friction independent of velocity? What evidence do you have?
- List 3 possible sources of uncertainty in your measurements.

END OF LAB

Was this lab useful, instructive, and did it work well? If not, send an email to thatlabsucked@gmail.com and tell us your issues. In the subject line, be sure to reference the your course, the experiment, and session. example subject: *PHYS1010 Linear Motion monday 2:30.* We won't promise a response, but we will promise to read and consider all feedback.