6. Friction, Experiment and Theory

The lab this week investigates the frictional force and the physical interpretation of the coefficient of friction. We will make use of the concepts of the force of gravity, the normal force, the frictional force, tension, free-body diagrams, and objects sliding on an inclined plane. The equipment used will be blocks with a variety of backings, an adjustable inclined plane and a motion sensor with GLX data collecting interface.

It is usually found experimentally that the force required to slide one object over another is proportional to the normal force pressing the surfaces together as expressed by

\[ F_f = \mu N \]

where \( \mu \) is called the “coefficient of friction” and represents the roughness of the surfaces in contact. One intuitively feels that the force should also depend upon such things as the area of contact and the speed of motion. Let us study the question experimentally and theoretically.

In order to express the reality that it is harder to make an object start moving than to keep the object moving, we can discuss the coefficient of static (not moving) friction \( \mu_s \) (to get it moving) versus the coefficient of kinetic (in motion) friction \( \mu_k \) (to keep it moving). In general, \( \mu_s \geq \mu_k \).

To study the question theoretically consider the online simulation at

[http://mail.mcm.edu/~bykov.tikhon/demos/physlets/lab5.html](http://mail.mcm.edu/~bykov.tikhon/demos/physlets/lab5.html)

It represents two blocks connected by a string, where one block is located on the table and another block is hanging from the table. The simulation allows changing mass of each of the blocks as well as the coefficient of friction between the block and the table. Try various values for masses and friction coefficients, see what happens. Notice how acceleration of the system changes as you change these variables. Determine the unknown values for masses and coefficient of kinetic friction.
1. The experimental design for the first part of the lab will be very similar to what you saw in the online demonstration. You will be using a block connected by a string with an additional mass hanging from the table. You should also set up the motion sensor in such a way that it allows you to measure the speed of the block. This way you can determine whether or not the block is accelerating as it moves along the board. Using this experimental setup with a horizontal surface, figure out which quantities you should plot on the graph in order to determine the coefficient of friction for the block sliding on the board. Hints 1 and 2 may help to figure this out. Does this graph give $\mu_k$ or $\mu_s$? Does $\mu$ depend on the value of either $F_f$ or $N$?

The provided blocks of wood have hooks for pulling and have various materials attached to them to vary the surface in contact. Figure out how to measure the normal force and the frictional force while the block is sliding across the board. See Hints 3 and 4 for help figuring out how to do this. Vary $N$ (for five values) and measure the corresponding $F_f$ for a given block. Make a plot and have Excel calculate the coefficient of friction, $\mu$, from the graph.

Repeat for two more blocks. Include all three plots on the same graph (put a legend on the graph). Which surface has the highest $\mu$? Does that make sense?

2. Set the surface at an angle $\theta$ from the horizontal. Place the object on the surface and increase the angle until it slides. The angle at which the object just begins to move is defined as the “angle of repose”. Figure 1 illustrates this situation. From the diagrams, it can be shown that there exists a relationship between the angle of repose, $\theta$, and the coefficient of friction, $\mu$. Determine this relationship and solve for $\mu$ in each case. Does this relationship give $\mu_k$ or $\mu_s$? (It may help to reread the third paragraph of this lab and then see Hint 5.)
Using the same blocks as before, compare your results with those determined in Step 1.

3. Select a block and an angle. Compute the force required to slide (pull) the object up the inclined plane (See Fig. 2) using the value of $\mu$ determined in Steps 1 and 2. Carry out the experiment and compare (via %-difference) the experimental value with the theoretical value for that type of material. Once again you can use the motion sensor to control whether or not the block is accelerating. See Hint 6 for help.

4. If you still have some time left, determine experimentally the effect of surface area and velocity upon the coefficient of friction of wood-on-wood. Discuss your results.
Hinting Questions for the Friction Lab

These questions should guide you through the lab if you are having trouble figuring out what to do. This is the sixth lab; you will be expected to come up with questions like these on your own next week. Pay attention to the types of questions you must ask yourself.

1. Calculating $\mu = \frac{F_f}{N}$ for each individual value is a reasonable approximation for $\mu$ but this is one measurement which has random error (error which can be reduced by increasing the statistics, i.e., by repeating the measurement many times). In the “Acceleration due to Gravity”-lab, did you get a better result for the acceleration due to gravity from the slope of $v$ vs. $t$ or from averaging the individual $a$ values?

2. Compare $F_f = \mu N + 0$ to $y = mx + b$. What should you plot as the ordinate (vertical axis) and as the abscissa (horizontal axis)? What property of the graph gives the coefficient of friction, $\mu$?

3. The normal force is not conceptually equal to the force of gravity, although in some cases these are numerically equal. (Recall that a bathroom scale does not read your weight, it explicitly reads the normal force you are exerting on the scale.) If you are using some block, how can you vary (i.e., pick and use a specific value of) the normal force which is exerted on the block?

4. If an object is being slowed by a frictional force, you can indirectly measure that backwards force by introducing an additional, measurable force which brings the net force to zero, i.e., which brings the block into equilibrium. Remember that equilibrium is a state in which the acceleration is zero. Can an object move when it is in equilibrium? (What is the difference between static equilibrium and kinetic equilibrium?) How can you pull an object across a board with a specific, known force?
5. Are we considering the block during its motion or are we considering it as it begins to move?

6. Once you know the gravitational force acting on the block, the applied force is the only variable that is not predetermined (because you have already determined $\mu$). Solve for the applied force. See Hint 7 if you need more help.

7. If you know the gravitational force, then you can break it into its components: along the incline and into the incline. From this we can find the normal force. From that, with $\mu$ known, we can find the frictional force. The only unknown left is the applied force. Solve $\vec{F}_{net} = ma$ for the applied force. How much weight must be placed on the hanger?