Lab V

Friction

1 Introduction

The purpose of this lab is to study frictional force, both static and kinetic.

2 Theory

Frictional forces arise as a result of short-ranged interactions between ‘rough’ surfaces. At an atomic scale, nearly all surfaces are ‘rough’, hence friction is a very common phenomenon.

Frictional forces occur on the interface between two surfaces, and act in a direction parallel to the interface to oppose any relative motion between the two surfaces (see Fig. V.1).

Static friction is a frictional force between two surfaces when the two surfaces are at rest with respect to one another. Kinetic friction occurs when there is relative motion between two surfaces.

In both cases, the frictional force depends on the ‘Normal force’: the force perpendicular to the interface between the surfaces, that squeezes the surfaces together.

The force from static friction will only be enough to oppose other forces that tend to make the surfaces slide against one another, up to a maximum, $F_{s}^{\text{max}}$. If the other forces exceed $F_{s}^{\text{max}}$, then the object will experience a net force and start to move. Once movement has started, there is a change to kinetic friction, which typically has a smaller frictional force than static friction (see Fig. V.2).

We can characterize the maximum static friction by using a coefficient of friction that relates the normal force to the frictional force. Coefficients of friction vary
Figure V.1: Frictional forces opposes the horizontal push. The ‘normal’ force is the force between the surfaces experiencing friction.

Figure V.2: Static friction is equal to the applied force up to a maximum when the object ‘breaks loose’. When the object is moving, kinetic friction opposes motion.

depending on the materials and the condition of their surfaces. For static friction:

\[ F_{s}^{\text{max}} = \mu_s F_{\text{norm}} \quad \text{(V.1)} \]

Where \( \mu_s \) is the coefficient of static friction and \( F_{\text{norm}} \) is the magnitude of normal force.

Kinetic friction is characterized by a similar relationship:

\[ F_k = \mu_k F_{\text{norm}} \quad \text{(V.2)} \]
Where $\mu_k$ is the coefficient of kinetic friction. Kinetic friction, in its simplest form, is independent of velocity as long as the velocity is non-zero.

The coefficient of kinetic friction is very commonly smaller than the coefficient of static friction, so that once sufficient force has been applied to an object to overcome static friction and get it moving, the frictional force opposing motion drops to the lower 'kinetic' value.

One result of this difference between static and kinetic friction is 'stick-slip' behavior at low speeds, where an object alternately sticks until sufficient force builds up, then slipping until brought to rest. This type of behavior is seen in situations such as geologic faults, where seismic forces build until a sudden 'slip' results in an earthquake.

To measure static friction, we will apply a transverse force to a 'sled' resting on the lab bench until it begins to slip. Plotting the transverse force needed to overcome friction vs. the normal force on the sled gives a slope that is the coefficient of static friction.
3 Pre-Lab

1. Draw a free body diagram of the forces on the sled and the weight holder for the kinetic friction setup.

2. Using your analysis of the free-body diagram, derive an equation for the acceleration of the sled in terms of the mass of the sled, the mass on the weight holder, and the coefficient of kinetic friction.
4 Procedure

4.1 Static Friction

Figure V.3: Side view of friction sled setup.

1. Use the table clamp and the wood spacer to attach the pulley to the edge of the table. Make sure that the pulley is set so that it is at the same height as the eye-bolt on the sled, and that the string path downward is not blocked (see Fig. V.3).

2. Tape a piece of smooth paper to the table (blank printer paper is good) to use as a friction surface for the sled to sit on. Tape the paper only on the edge away from the pulley, so that the force of the sled on the paper will pull the paper tight, and not cause it to buckle.

3. Weigh the sled and mass holder and enter the results in Table V.1.

4. Tie the string to the eye-bolt on the sled, then pass the string over the pulley and tie the other end to the mass holder.

5. Start with no masses added to the sled.

6. Put a mark on the paper next to the sled. You will bring the sled back to this mark for each static friction measurement.
7. Add masses (gently!) to the mass holder until the sled starts to move, using smaller and smaller masses to find the smallest transverse force that overcomes static friction. Remember to bring the sled back to your mark each time it starts to move.

8. Take the masses off the mass holder and weigh them, enter the data in Table V.2.

9. Weigh a 50 g or 100 g mass and add it to the sled. Repeat the above steps for different total mass added to the sled until you fill Table V.2. Add your masses to the center of the sled, or distributed evenly from front to back.

10. Using the fitting software (see Appendix B) to fit and plot \( F_{\text{norm}} \) on the \( x\)-axis vs. \( F_{\text{pull}} \) on the \( y\)-axis. Enter the results of the fit on the data sheet, and calculate the coefficient of static friction. Turn in your plot with your data.

Tape the supplied plastic sheet to the table under the sled (again, only tape the edge away from the pulley), and repeat the steps above, entering your data in Table V.3. To put a mark on the plastic sheet, use masking tape.

### 4.2 Kinetic Friction

1. With the same setup of the sled on the plastic sheet that you used in the previous part, put another mark on the plastic sheet roughly 10 cm from the first mark. Both marks should be to the side of the sled’s path. There should be some room on the sheet so that the sled can start moving before it passes the first mark, and that it is still completely on the sheet when it passes the second mark (see Fig. V.4).

2. Put some mass to the mass holder, entering the total mass of the weight holder + added masses in Table V.4.

3. Add or subtract masses from the sled until you get a slow, steady motion between the two marks. You should ‘time’ the motion by stop watch (or just by counting), trying to get a consistent time of 2 to 3 seconds for the sled to travel between your marks. Note that you are not measuring velocity accurately, just trying to get consistency in your measurements. You will probably need to prod the sled to get it moving (i.e. to overcome static friction), but after that it should move on its own.

4. Make sure that masses you add to the sled are evenly distributed in the sled.
Figure V.4: Kinetic friction setup as viewed from above. The sled moves from left to right, starting to the left of the marks.

5. When your sled's motion between the marks is reasonably slow and steady, record the total mass of the sled + added weights in Table V.4. Note that there will be some variation in the speed of the sled because of variations in the surface; try timing the motion of the sled a few times to make sure it is consistent.

6. Add 50 g or 100 g to the mass holder and repeat your measurements until Table V.4 is filled.

7. Like the previous part, plot $F_{\text{norm}}$ vs. $F_{\text{pull}}$ and turn in your plot with your data. The slope of this graph is the kinetic friction of the sled against the plastic sheet.
5 Data

Table V.1: Masses

\[ M_{\text{sled}} = \quad \text{[kg]} \]

\[ M_{\text{holder}} = \quad \text{[kg]} \]

Table V.2: Static friction, sled against paper.

<table>
<thead>
<tr>
<th>( M_{\text{sled+weights}} )</th>
<th>( M_{\text{holder+weights}} )</th>
<th>( F_{\text{norm}} = M_n g )</th>
<th>( F_{\text{pull}} = M_p g )</th>
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Slope of \( F_{\text{pull}} \) vs. \( F_{\text{norm}} \) = \( \mu_s \): \[ \]

Intercept on \( F_{\text{norm}} \) axis: \[ \]
<table>
<thead>
<tr>
<th>$M_{sled+weights}$</th>
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Slope of $F_{pull}$ vs. $F_{norm} = \mu_s$: ____________

Intercept on $F_{norm}$ axis: ____________
Table V.4: Kinetic friction, sled against plastic sheet.

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<tr>
<th>$M_{\text{sled }\text{+ weights}}$</th>
<th>$M_{\text{holder }\text{+ weights}}$</th>
<th>$F_{\text{norm}} = M_{n}g$</th>
<th>$F_{\text{pull}} = M_{p}g$</th>
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Slope of $F_{\text{pull}}$ vs. $F_{\text{norm}} = \mu_{s}$: ___________

Intercept on $F_{\text{norm}}$ axis: ___________
6 Conclusions

1. According to your results, is it a good description of static friction to say that it is a linear function of the normal force? Why or why not?

2. Compare your values for $\mu_s$ for the sled against paper to that for sled against the plastic sheet. Is it consistent with what you would expect for the two surfaces?

3. Compare the value you got for static and kinetic friction coefficients of the sled on the plastic sheet. Are they consistent with what you would expect?

4. When you plot $F_{\text{norm}}$ vs. $F_{\text{pull}}$ for kinetic friction and fit to a line, do you have a non-zero intercept? What real effects could be causing a non-zero intercept?