PHYS 31, SCU Physics Dept., Winter 2021 (online)

Name: Jason

Lab Partners: Emilio, Edmund, Leanne

# Lab 5: Friction

## Introduction:

There are two types of friction: kinetic and static. Kinetic friction is the friction between surfaces in relative motion. When an object slides across another surface, microscopic bumps and defects tend to impede and resist the motion. Experimentally, it is observed that the force of kinetic friction is proportional to the normal force $\vec{F}_N$ acting between the surfaces in contact with one another: if you increase the normal force, the surfaces are crushed more together, increasing the effective contact area and thus increasing the frictional force. Mathematically, we can write the force of kinetic friction as

$$|\vec{F}_k| = \mu_k |\vec{F}_N| \tag{1}$$

The *coefficient of kinetic friction* $\mu_k$ is a dimensionless quantity that depends on the properties of the two surfaces. $\mu_k$ ranges from 0.01 for very smooth surfaces to 1.5 for very rough surfaces.

Static friction describes the frictional forces between the surfaces of two objects that are at rest with respect to each other. The static friction between the two surfaces is described by the *coefficient of static friction* $\mu_s$. Experimentally, is it found that the maximum value for the static frictional force is proportional to the normal force between the two surfaces. Thus, the static frictional force $F_s$ is

$$|\vec{F}_s| \leq \mu_s |\vec{F}_N| \tag{2}$$

For almost all objects $\mu_s > \mu_k$, since molecular bonds between surfaces form more easily in the static case. This means that greater force is needed to start an object in motion than to keep the object it in motion. Graphically, this effect is shown in Figure 1: As a horizontal applied force $F_{ext}$ is increased on a resting object, the static friction force increases linearly until the applied force $F_{ext}$ equals $\mu_s F_N$. After this point the object "breaks away" and the frictional force falls to its kinetic friction value.

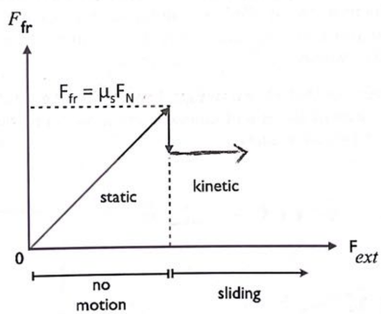



Figure 1: (a) Force of friction ($F_{fr}$) as a function of an external force ($F_{ext}$) applied to an object that is initially at rest.

The main goals of this lab are to understand the relationship between the frictional force and the normal force acting an object, and to calculate the kinetic and static coefficients of friction for various objects on different surfaces.

## Part 1: Coefficient of Static Friction

1. You will use the PhET applet "Friction" found here to measure the coefficient of static friction $\mu_s$ between a wooden crate and the horizontal surface shown in Fig. 2. The applet allows you to apply a horizontal force on the crate in increments as small as 1 N. In this exercise, you should NOT move the scroll bar for friction (in the upper right box). Doing so would change the value of $\mu_s$.

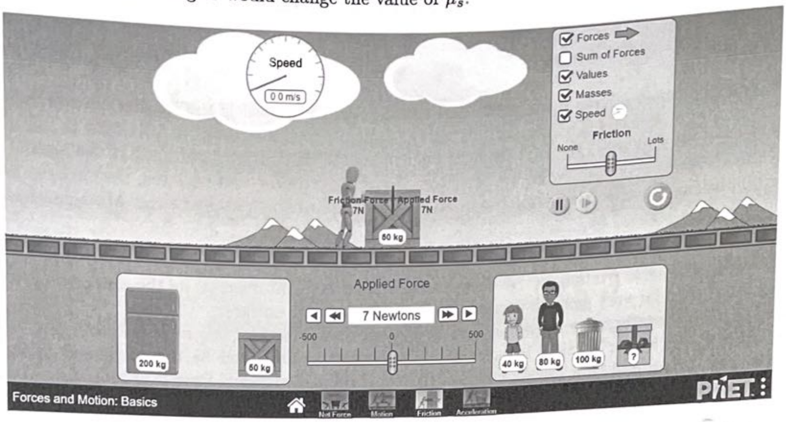



Figure 2: User interface window for studying friction.

$W = mg$

$W = (50\,kg)(9.8\,m/s^2)$

2. Record the mass and weight of the wooden crate:

   Mass = 50 kg, Weight = 490 N

3. Increase the applied force acting horizontally on the crate using the scroll bar and/or the arrows above it. Monitoring the value of this force, determine the *minimum* force needed for the crate to "break away" and start moving. You can increase the applied force in larger step size at the beginning, but make sure you reduce the increment to 1 N as you approach the "break away" value. Practice the exercise a few times until you understand how the applet works.

4. Sketch a force graph similar to that shown in Fig. 1 that semi-quantitatively describes the experiment you just performed. Label the regions of static and kinetic friction on your graph and specify the value of the applied force where the crate first begins to move.

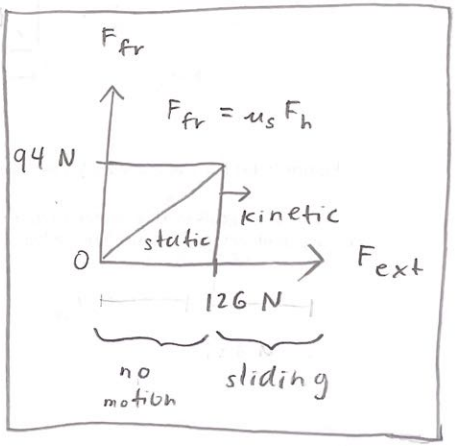
Minimum force: 126 N

$F_{net}$

→ 32 N

$F_{fr}$ 94 N | 50 kg | $F_{App}$ 126 N

Force Graph



5. Repeat the procedure 5 more times (for a total of 6 data points) using different known "crate" masses. (You can stack various objects, except for the refrigerator, on top of the wooden crate.) Record the *minimum* force needed in each case to start the crate moving. Define the units at the top of each column.

| Total Mass | Calculated Normal Force ($F_N$) | Minimum Force for the Box to Start Moving |
|---|---|---|
| 100 kg | 980 N | 264 N |
| 90 kg | 882 N | 232 N |
| 130 kg | 1274 N | 337 N |
| 180 kg | 1764 N | 466 N |
| 140 kg | 1372 N | 360 N |
| 50 kg | 490 N | 129 N |

6. Carefully plot on graph paper the minimum force required for your box to move as a function of the normal force of the various (stacked) objects. Draw a line of best fit through your data points. Calculate the slope and explain what it represents. Be sure to keep track of units.

Slope= $y = 0.2634x$ Here, the slope of 0.2634 is the static friction coefficient.

7. Select the mystery object (the gift box), which you should assume is also made of wood. Using your experimental value for $\mu_s$ above, describe in two or three sentences how you can determine the mass of the mystery object using the above experimental technique along with Newton's Laws.

- To calculate the mass of the mystery object, first calculate the normal force using $F_N = mg$. To get that, we use $F_N = \frac{F_{fr}}{u_s}$, which is the friction force over the static friction coefficient.

Carry out your idea to determine the mass of the object. Show your work.

Mass = 37.19 kg

$F_{fr} = u_s F_n$

$F_n = F_{fr} / \mu_s$

$F_n = (96 \text{ N}) / (0.2634)$

$F_n = 364.46 \text{ N}$

$F_n = mg$

$364.46 = mg$

$m = F_n / g$

$m = \frac{364.46 \text{ N}}{9.8 \text{ m/s}^2}$

$m = 37.19 \text{ kg}$

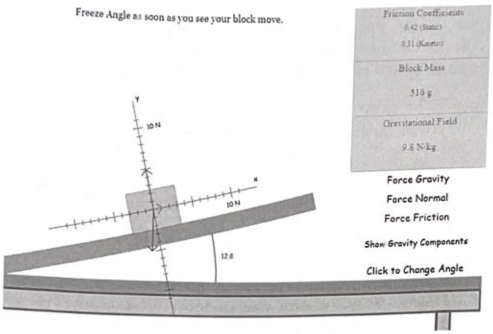



Figure 3: Simulation window for studying friction using an inclined plane. The user can adjust the incline angle $\theta$.

8. Next, you will use the Physics Aviary app found here (see Fig. 3) to study friction using an inclined plane and an object that begins at rest. Start the simulation and record the value of coefficient of static friction provided.
   $\mu_s =$ 0.41

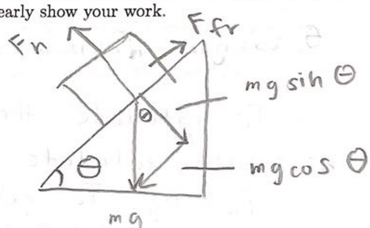
9. Slowly increase the angle ($\theta$) of the incline. What do you observe?
   When the angle increases, the gravitational force acting on the object becomes a stronger influence, and the sheer mass of the object overcomes the frictional force, eventually causing the object to slip.

10. Use a free body diagram and Newton's 2nd Law to derive a general expression for the minimum incline angle $\theta_{min}$ needed for the object shown in Fig. 3 to "break away" and start moving down the ramp. Your general expression should include the coefficient of static friction. Clearly show your work.

$F_n = mg$

$mg \sin\theta = \mu_s mg \cos\theta$

$\mu_s = \dfrac{\sin\theta}{\cos\theta} = \tan\theta$




11. Use the values for the coefficient of static friction provided by the simulation to calculate the theoretical minimum angle to "break away".
    $\theta_{theoretical} =$ $22.29^\circ$

$\tan^{-1}\theta \rightarrow \tan^{-1}(0.49) = 22.29^\circ$

12. Now experimentally measure the angle $\theta_{min}$ that barely starts the object moving. Slowly increase the angle of the ramp (starting from $\theta = 0$) and "freeze" the system the moment the object starts to slide. Do the experiment three times and record your results for the three trials, below. Include a good estimate of your uncertainty for each trial.
    $\theta_1 =$ 22.3 $\pm$ 0.01, $\theta_2 =$ 22.4 $\pm$ 0.11,
    $\theta_3 =$ 22.6 $\pm$ 0.31, $\theta_{ave} =$ 22.43 $\pm$ 0.143.

13. Clearly explain how you estimated the uncertainty in your angle measurements. *Hints:* Think about your reaction time when performing the experiments. Also, review how to get the uncertainty of an average using error propagation methods.

- I estimated the uncertainty in the angle measurements by calculating the difference between the last time I froze the angle and the last time I froze the angle before the object started to slide.

14. Explicitly consider your experimental uncertainty reported above and compare your theoretical and experimental values of $\theta_{min}$.

Given an average uncertainty of 0.143 degrees, my theoretical angle of 22.29° and my average experimental value of 22.43° are within the uncertainty range, thus are accurate values.

**Part 2: Coefficient of Kinetic Friction**

You will use the java applet found here to study the effects of kinetic friction. Open the applet and select the "Force Graphs" tab. The user interface window is shown in Fig. 4.

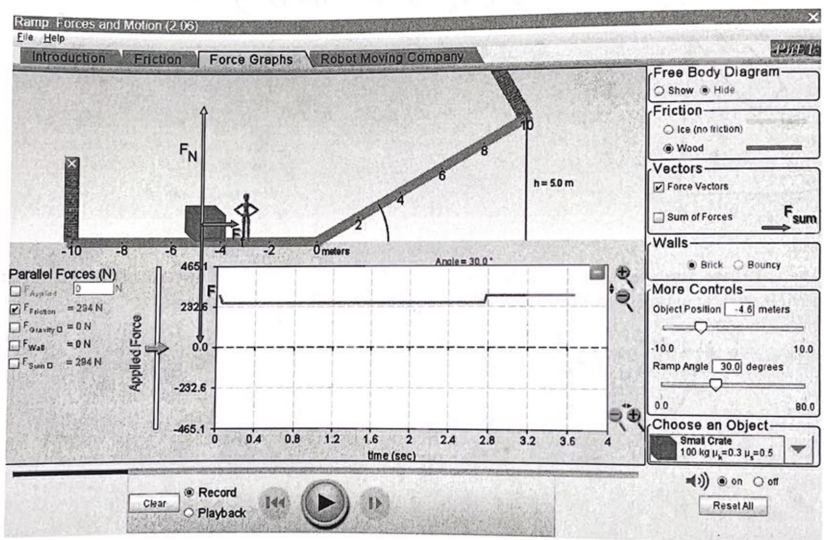



Figure 4: Simulation window for studying the kinetic friction acting on an object as it slides down an inclined plane.

1. Choose "Small Crate" as your object, "Brick" for the wall and "Wood" for friction. Set the ramp angle to 30° and the object's position to 8.9 m (top of the ramp). Select the friction force $F_{friction}$ to be displayed in the "Applied Force vs. Time" graph. (You should "un-click" all other forces to avoid confusion.) Release the box from rest and stop it only after passes the end of the incline. Carefully examine the "$F_{friction}$ vs. Time" graph generated during the motion. Notice the two distinct regions of data, corresponding to: *(i)* the crate sliding down the incline, and *(ii)* the crate sliding along the horizontal surface. Use the graph to find the time it took the crate to travel the length of the incline. You should zoom-in on the graph to get the most accurate readings possible.

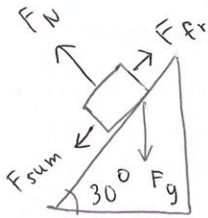
$t =$ 2.8 $\pm$ 0.1

Clearly explain how you estimated uncertainty in time measurement.

I measured the uncertainty using the standard human error measurement, which is determined off of the average human failure for reaction time. 0.1 would be an appropriate point because my measurements aren't necessarily precise. I make the most I can by zooming into the graph to determine the truest value of the data point.

2. Draw a free body diagram for the crate as it slides down the incline. Use the diagram to write-down the corresponding Newton's 2nd Law equations for the motion. Then use your equations to show that the acceleration of the crate as it slides down the incline is:

$$a = g(\mu_k cos\theta - sin\theta) \quad (3)$$




$a = g(\mu_k \cos\theta - \sin\theta)$

$= 9.8(0.3\cos(30) - \sin(30))$

$a = -2.35 \ m/s^2$

3. Now calculate the acceleration of the crate using kinematics equations instead of forces. (Hint: Is the crate moving with constant acceleration along a straight-line path ?) Show your work.

$a =$ $-1.135 \ m/s^2$

$a = \frac{x}{t^2} = \frac{-8.9 \ m}{(2.8 \ s)^2} = -1.135 \ m/s^2$

$x = \frac{1}{2}at^2 = \frac{1}{2}(-1.135)(2.8)^2 = 4.45$

$A = \frac{2(4.45)}{(2.8)^2} = \frac{-8.9}{(2.8)^2} = -1.135 \ m/s^2$

4. Use Eq. 3 and the acceleration of the crate as calculated above to determine the coefficient of kinetic friction between the crate and the inclined plane. Then compare your experimental value of $\mu_k$ to the value provided by the simulation. Show your work.

$\mu_k =$ 0.44

$\Sigma F = ma$

$a = g(\mu_k \cos\theta - \sin\theta)$

$a = 9.8\ m/s^2(\mu_k \cos\theta - \sin\theta)$

$-1.135\ m/s^2 = 9.8\ m/s^2(\mu_k \cos 30° - \sin 30°)$

$-1.135\ m/s^2 = 8.48705\ \mu_k - 4.9$

$3.765\ m/s^2 = 8.48705\ \mu_k$

$\mu_k = 0.44$

5. Mystery object! Select the "Mystery Object" from the drop down menu. Using the same experimental procedure as above, determine the coefficient of kinetic friction between the mystery object and the incline. Show work.

$t_1 =$ 2.4 s $t_2 =$ 2.45 s $t_3 =$ 2.35 s

$t_{avg.} =$ 2.4 s $a =$ $-1.55\ m/s^2$

Mystery $\mu_k =$ 0.44

$t_1 = 2.4s,\quad t_2 = 2.45s,\quad t_3 = 2.35s$

$$a = \frac{x}{t^2} = \frac{(-8.9\,m)}{(2.4s)^2} = -1.55\ m/s^2$$

$-1.55\ m/s^2 = 9.8\ m/s^2(\mu_k \cos(30) - \sin(30))$

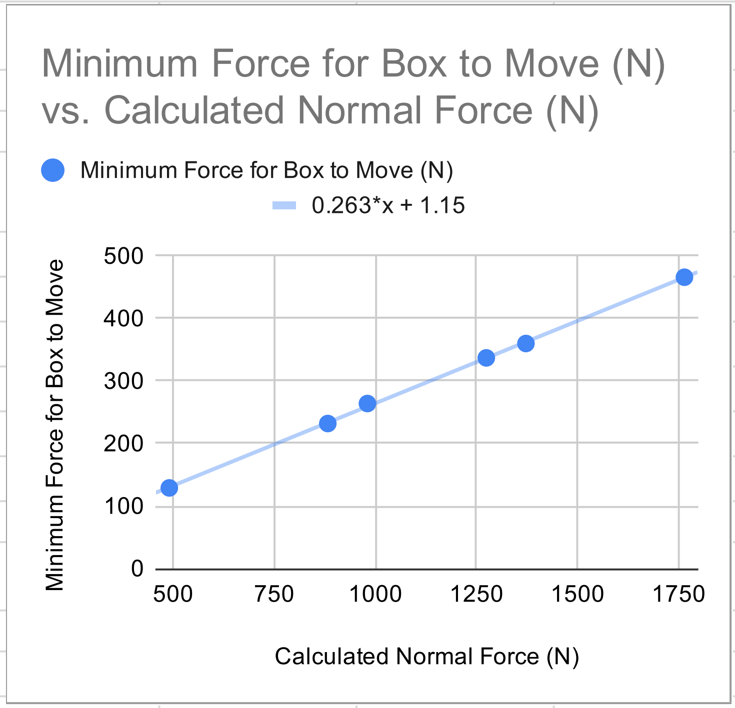
$-1.55\ m/s^2 = 8.48705\ \mu_k - 4.9$

$3.35\ m/s^2 = 8.48705\ \mu_k$

$\mu_k = 0.44$

# Part 1: Question 6

| Calculated Normal Force (N) | Minimum Force for Box to Move (N) |
|---|---|
| 980 | 264 |
| 882 | 232 |
| 1274 | 337 |
| 1764 | 466 |
| 1372 | 360 |
| 490 | 129 |




# Part 1: Question 11

| Team Member | Theoretical Angle |
|---|---|
| **Jason** | 22.29 degrees |
| **Emilio** | 21.31 degrees |
| **Edmund** | 21.3 degrees |
| **Leanne** | 22.2 degrees |

# Part 1: Question 12

| Team Member | Average Experimental Value |
|---|---|
| **Jason** | $22.43 \pm 0.143$ |
| **Emilio** | $21.4 \pm 0.3$ |
| **Edmund** | $21.4 \pm 0.1$ |
| **Leanne** | $22.1 \pm 0.1$ |

# Part 2: Question 5

| Team Member | Mystery μk |
|---|---|
| **Jason** | 0.4 |
| **Emilio** | 0.404 |
| **Edmund** | 0.395 |
| **Leanne** | 0.39 |