

LAB V. FRICTION

1. Objectives

This experiment focuses on studying the friction between two surfaces. You will learn how to use Newton's 2nd law to find the force and acceleration of an object. Then, using Tracker, you will be able to estimate the kinematic properties of the system. In the end, you will find the static and kinetic friction coefficients.

2. Material (see **Fig. 1**)

- A Hockey puck or a sliding object
- A Meter stick/ruler
- A Scale (Kitchen scale)
- A Wooden/metallic surface
- A tripod
- 2/3 books

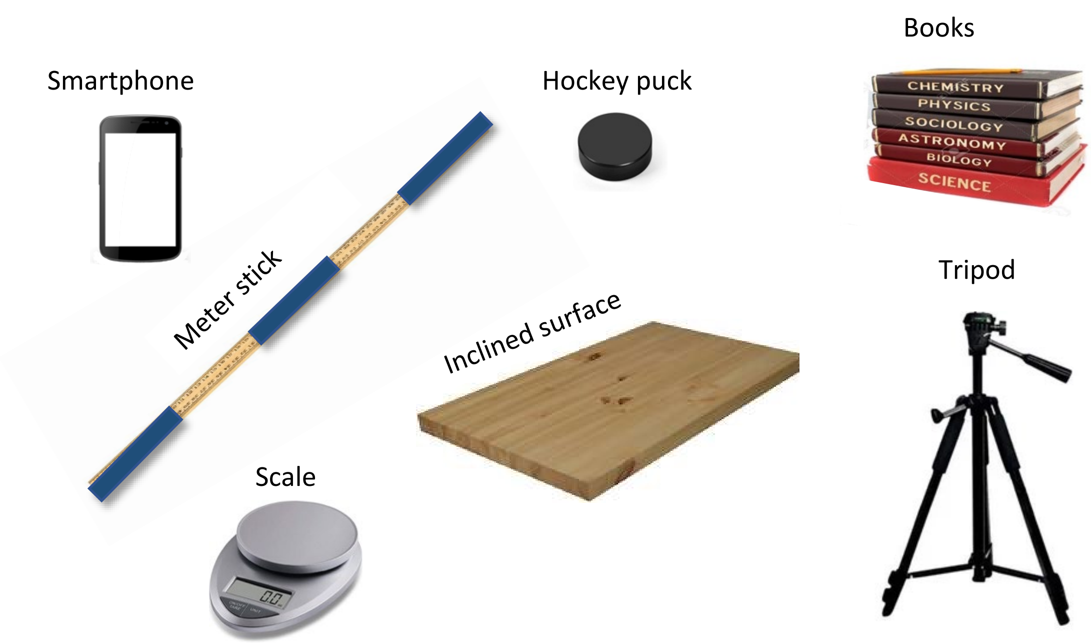

Fig. 1: An example list of materials used in this lab.

3. Theory

3.1 Newton's 2nd law

If you put an object on an inclined surface, you would expect it to either stay there or start sliding downward. This can be all explained by the applied forces on the object. Using Newton's 2nd law, one can write down the equations for forces applied in two dimensions. One is along the inclined surface (x axis) and the other along the normal to the surface (y axis) as shown in **Fig. 2**,

$$\begin{cases} \sum F_x = ma_x, \\ \sum F_y = ma_y, \end{cases} \tag{1}$$

where *m* is the mass of the object and a_x, a_y are the components of the acceleration along the *x*- and *y*-axes. The force that tries to pull down the object is the gravitational force W (mg). Based on the coordinate system defined in the diagram, the components are

$$\begin{cases} W_x = W \sin\theta = mg \sin\theta, \\ W_y = W \cos\theta = mg \cos\theta\,, \end{cases} \tag{2}$$

If the surface is solid, you would not expect the object to deform the surface or have any motion in the *y* direction. This means there should be another force that cancels the W_y in the *y* axis. That force is called *Normal* force N, and it is from the solid surface toward the object. **Equation. 2** can then be written as,

$$\sum F_y = mg\cos\theta - N = 0. \tag{3}$$

The remaining force in the diagram is the friction force f which always points in the oppostite direction to the movement. In this scenario, the object tends to move downward, so the friction should be upward. The two types of friction forces that are considered in this lab are

3.2 Static Friction:

If the object is stationary or $a_x = 0$ in **Eq.** 1, the friction force is exactly canceling the gravitational force (W_x). This is called static friction f_s which is equal in magnitude and opposite in direction to the applied forces. If you increase the gravitational force (W_x) (changing θ) or push the object with your hand, at some point, the object may start moving. This means you no longer have static friction. The upper limit of the static friction force that prevents the object would be,

$$f_s = \mu_s N = \mu_s mg\cos\theta, \tag{4}$$

where μ_s is the static friction coefficient and depends on the materials and properties of the two touching surfaces.

3.3Kinetic Friction:

If $a_x \neq 0$, the friction force is not equal to the applied force, but it still exists there. This friction is called kinetic friction f_k which can be similarly found for any surfaces as,

$$f_k = \mu_k N = \mu_k mg\cos\theta, \tag{5}$$

where μ_k is the kinetic friction coefficient.

Based on the coordinate system shown in **Fig. 2**, the total force in y direction would be zero. With the friction force defined as in **Eq. 6**, the **Eq. 2** can be simplified as,

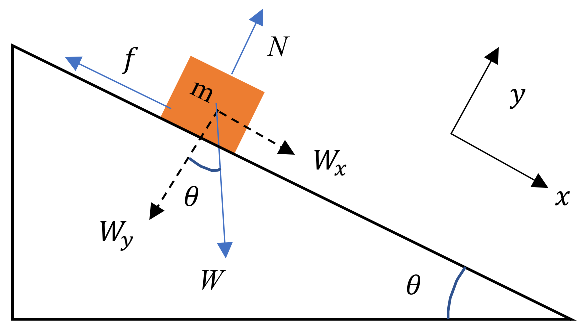

Fig. 2: Free body diagram

$$\sum F_x = mg\sin\theta - \mu_k mg\cos\theta = ma_x, \tag{6}$$

where a_x can now be written as,

$$a_x = g\sin\theta - \mu_k g\cos\theta. \tag{7}$$

4. Lab Setup preparation

There are several instructional videos on the preparation of the lab. You need to watch

(1) **Preparing the Meterstick** video (https://www.youtube.com/watch?v=67j4kJOiAQI)

(2) **Phone Setup** video (https://www.youtube.com/watch?v=nHfeejFBe28)

(3) **Tracker Tutorial** video

(https://www.youtube.com/watch?v=BxplFubEVzQ)

Please make sure that you follow the detailed instructions to avoid potential errors in data analysis before attempting to perform the experiment.

A detailed video instruction on how to prepare and perform Friction experiment can be found at :

https://www.youtube.com/watch?v=Yp0iVhh5xy4

4.1 Preparing the inclined plane

4.1.1 Create a smooth inclined surface using books, notebooks, wooden surface, metal surface etc.

4.1.2 The surface should be free of any dents or irregular shapes and needs to be solid. Any deformation during the experiment or nonuniform composition of material can cause significant error in your analysis.

4.1.3 The bottom of the surface should be fixed. You should be able to adjust the angle of the surface without moving it translationally. During this lab, you will be asked to perform several trials at different initial angles.

4.1.4 Make sure the side edges of the surface exactly line up with the length scale

4.2 Sliding motion

4.2.1 Use an object that has a uniform surface and does not rotate (roll) while sliding on the inclined plane.

4.2.2 Sliding motion should happen at the edge of the plane. This means it should also match the length scale.

4.2.3 Tracker app should be able to track a certain point of the object
  a. Use playdough to make tracking easier
  b. Tracking the object works better for good color contrast with the background

5. Experiment & Data Analysis Procedure

First, the focus will be on understanding normal force and static friction. You will not need the Tracker app to measure any dynamics of the system. In this second part, focus is on the kinetic friction and its dependence on the initial angle. You will try several scenarios including using different objects and kicking object upward on the surface.

5.1 Normal Force

5.1.1 *Flat surface*: Measure the mass of the object on a flat surface. Record that mass.

5.1.2 *Incline surface*: Make an inclined surface at a relatively small angle ($< 5°$)

5.1.3 *Measure new mass*: Place the scale on the inclined surface. Zero the scale. Place the object on the scale and record the new mass. Make sure the scale or the object are stationary. Record the new weight.

5.1.4 *Higher angles*: Remove the object, increase the angle by the same amount and zero the scale again. Measure the mass of the object again. Perform these steps for at least 4 higher angles.

5.1.5 *Normal force* : According to the **Eq. 4**, the normal force is proportional to a cosine function. Therefore, the mass ratio of the reduced mass over the original mass ($\frac{m'}{m}$) also follows the cosine function. Compare $\cos\theta_0$ with $\frac{m'}{m}$ and fill in **Table. 1**.

5.2 Static Friction

5.2.1 *Incline surface*: Place the object on the inclined plane. You no longer need the scale in this section. Slowly increase the angle of the plane until the object starts sliding. Do not change the angle anymore.

5.2.2 *Angle measurement*: Your goal is now to measure the angle accurately. Record a short video with the mounted phone and use Tracker to find the angle. Perform the previous steps at least 5 times.

5.2.3 *Static friction coefficient derivation*: Use Newton's 2nd law in **Eq. 1** find μ_s in terms of θ. It should be noted that total force is zero for x and y components of the force. (*Hint: Use **Eqs. 2-4***)

5.2.4 *Static friction coefficient estimation*: Find μ_s for 5 trials, find the average and fill in **Table. 2**. Search online for the range of reasonable values of μ_s and see if your values are within that range.

5.3 Kinetic Friction (Sliding downward)

5.3.1 *Incline surface*: Place the object on the inclined plane. Make sure the angle is large enough that object slides downward. Record the sliding motion of the object at a fixed inclined plane angle in slow-mode.

5.3.2 *1D motion*: Rotate the coordinate system in the Tracker, so that the object has one dimensional motion. Repeat these steps at least 5 times for the same angle

5.3.3 *Kinetic friction*: Find the acceleration along the inclined surface by fitting a quadratic function to the tracked data. Please refer to the instructions for **Free fall** or **Projectile motion** if you have difficulty in finding the acceleration. Find μ_k using **Eq.7** for all the trials.

5.3.4 *Increase the initial angle*: Increase the angle of the plane by roughly 10 degrees. Follow steps 5.3.1 to 5.3.3. Increase the angle again and fill in the **Table. 3** for 5 different trials.

5.4 Kinetic Friction (Sliding upward)

5.4.1 *Incline surface*: Make the angle of the incline surface small enough so that the object does not slide downward.

5.4.2 *Kick the object upward*: Put the object at the bottom of the inclined surface. Slightly kick the object so that the object slides upward. It should eventually stop before dropping from the other end.

5.4.3 *Direction of friction*: With the object sliding upward, the direction of friction force changes. Write down Newton's 2nd law for this motion according to **Eqs. 1** and **6**.

5.4.4 Find μ_k for different initial incline angles, similar to steps 5.3.1 to 5.3.4. It must be noted that the object must be stationary at the beginning.

Lab V Worksheet

Name of the Student: ______________________ **Date: ______________________**

Q.1 Normal Force

m (mass of object): ----------------

Q.1.1 Fill in the table according to the procedure.

Table. 1

Trial	θ_0	m' (Measured mass)	$\frac{m'}{m}$	$\cos\theta_0$	Percent error
1					
2					
3					
4					
5					
6					

Q.1.2 How does $\frac{m'}{m}$ at different angles change?(increase, decrease, constant) Explain.

Q.1.2 What is the main source of difference between $\frac{m'}{m}$ and $\cos\theta_0$? Explain.

Q.2 Static Friction

Q.2.1 Derive the static friction coefficient μ_s in terms of the inclined plane angle θ_0.

Q.2.2 Use the expression found in *Q.2.1* and determine μ_s for 5 different measurements. Fill in the table:

Table. 2

Trial	θ_0	μ_s
1		
2		
3		
4		
5		
Average		

Q.3 Kinetic Friction (Sliding downward)

Q.3.1 Plot the velocity as a function of time for a single trial. Is this a motion with constant velocity or constant acceleration? Explain.

Q.3.2 Fit a quadratic function to the motion of the object, find the acceleration and estimate μ_k using **Eq. 7** for 5 trials.

Q.3.3 Fill in the table for 5 different trials done at 3 different angles. Does the acceleration depend on the angle? Explain.

Table. 3

$\theta_1 =$		$\theta_2 =$		$\theta_3 =$	
a	μ_k	a	μ_k	a	μ_k

Q.3.4 Calculate the average of μ_k for each angle. How does μ_k depend on the angles?

Q.4 Kinetic Friction (Sliding upward)

Q.4.1 Write down the Newton's 2nd law for an upward sliding motion (with a small initial kick) for x and y components, separately.

Q.4.2 How does this equation differ from the sliding downward motion in **Eqs. 6** and **7**? Explain the differences.

Q.4.3 Fill in the table for 5 different trials done at 3 different angles (**Note: object is stationary in the beginning, only moves after being kicked).** Does the acceleration depend on the angle? Explain.

Table. 4

$\theta_1 =$		$\theta_2 =$		$\theta_3 =$	
a	μ_k	a	μ_k	a	μ_k

Q.4.5 Calculate the average of μ_k for each angle. How does μ_k depend on the angles?

Q.4.6 Compare the μ_k calculated in Q.4.5 with the ones calculated in Q.3.4. Explain the possible sources of error.

Q.4.7 What aspects of the experiment would you do differently to obtain better results?

Troubleshooting

- The scale and the object on the scale should not move at all.
- If your scale or the object move
    - Tape the inclined surface or the scale to prevent movement
- The scale gives a negative number on the inclined surface with no mass on it
    - This is normal and is due to the mass of the plate of the scale. Zero the scale after each increase in the angle
- Do not use the ruler to estimate the angles. Make sure to use Tracker
- The object should not rotate (roll) in any direction.
- Any problems in mounting the phone can severely affect the accuracy of your results