LAB 3: FRICTION FORCES EVALUATION

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Abstract *This lab involves using a tracking camera and software to find the static and kinetic coefficients of friction between a block and an inclined plane. Multiple trials are performed for each kind of friction coefficient, and data is collected for both a smaller and larger side of the block. Collecting data for different surface sizes shows the relationship between surface area and the coefficient of friction. Data for static friction coefficients are collected by increasing the angle of the plane until the block starts to slide, whereas for kinetic friction coefficients, the plane is inclined at a fixed angle and the block is slid down the inclined plane. The data includes timestamps, the position, velocity, and acceleration for the block as well as certain points on the ramp to find its angle. Results deviated slightly from theoretical expectations, however, the consistency of the deviation between trials may point to faults in the lab equipment.*

Keywords: *coefficient of friction, force, acceleration, tracking, standard error*

1. Introduction

The purpose of this lab was to find the static and kinetic coefficients of friction between a wooden block and a metal ramp. The coefficient of static friction is calculated with the following formula:

$$\mu_s = \frac{d_y}{d_x}$$ ***Equation 1***

Where μ_s is the coefficient of static friction, d_x is the horizontal distance between a point on the inclined part of the ramp and the ramp's pivot point, and d_y is the vertical distance between a point on the inclined part of the ramp and the ramp's pivot point. d_x and d_y are taken at the point in time where the block starts to accelerate, meaning the force of static friction is overcome by the force of gravity. The coefficient of kinetic friction is calculated with the following equation:

$$\mu_k = \frac{g * sin(\theta) - a}{g * cos(\theta)}$$ ***Equation 2***

Where μ_k is the coefficient of kinetic friction, g is the gravitational acceleration constant on earth, θ is the angle of the ramp, and a is the acceleration of the block down the ramp. The angle of the ramp is given by the following equation:

$$\theta = arctan(\frac{d_y}{d_x})$$ ***Equation 3***

Where d_y and d_x are the same variables mentioned in **Equation 1**.

2. Experimental Procedure

Nine trials were conducted for both types of friction coefficients and both large and small sides of the wooden block, which means that thirty-six trials were conducted in total. Using the lab equipment required using the secure shell protocol to connect a host computer to the lab computer. The home directory of the lab computer included a folder of python scripts that allowed data collection through a tracking camera. One of these scripts was copied to the home directory and edited such that the camera distance variable was set correctly in order to accurately track the object's motion. Running this script generated a video of what the camera saw as well as a comma-separated values file containing frame number, timestamp, position, velocity, and acceleration data for all tracking points. Stickers indicating tracking points were placed on the wooden block, the pivot point of the ramp, near the top of the ramp, and lastly on the base of the ramp as shown below.

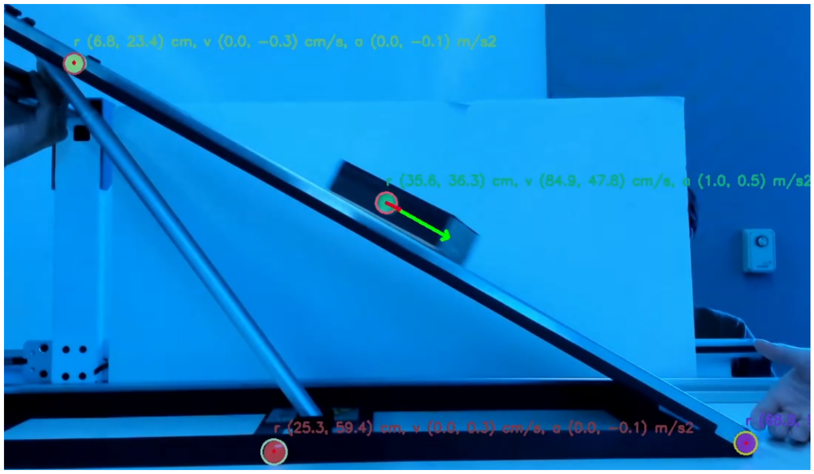

Figure 1: Tracking Points on the Ramp and Block

The script was run once for each side and friction type combination, with nine trials contained in each run, which generated four sets of data. Data was collected for the static coefficient by gradually increasing the angle of the ramp until the block started to accelerate downward. Data was collected for the kinetic coefficient by fixing the ramp at an angle and then letting the block slide down such that the camera can record the block's acceleration.

3. Results and Analysis

Results for the coefficient of static friction are shown in **Table 1** and results for the coefficient of kinetic friction are shown in **Table 2** below. Calculations for the coefficient of static friction were done for each trial by using **Equation 1**. The vertical and horizontal distances used in **Equation 1** were found by finding the difference between the horizontal and vertical positions of the yellow dot on the top of the ramp and the purple dot on the pivot point of the ramp. The exact frame where the block started to slide down was found by creating a plot between the frame numbers and the vertical position of the block, which was then used to find the frame where the vertical position of the block is maximized. This was done by reading the comma-separated values file into a Pandas dataframe using a Python script. Trials were isolated by selecting the rows where the horizontal velocity of the block is both positive and increasing. The resulting cleaned Pandas dataframe was then exported to a new comma-separated values file and opened in Microsoft Excel to plot and find the point of maximum vertical position for each trial. This was done for both the large and small sides of the wooden block. Uncertainty of the static friction coefficients was calculated by creating a Pandas series of all nine trials for both the large and small sides and calling the *.sem()* method on both Pandas series, which returns the standard error of the sample. Calculations for the coefficient of kinetic friction were done for each trial and both sides of the block by using **Equation 2**. The equation requires two variables: the angle of the ramp, and the acceleration of the block. The angle of the ramp was kept constant between trials and between the sides of the block. The angle of the ramp was found using **Equation 3**, where d_y and d_x are found by the same method described earlier. The acceleration of the block was found by first taking the mean of the vertical and horizontal acceleration of the block while sliding down the ramp, and then plugging each component into the Pythagorean theorem. The result is the acceleration of the block relative to the ramp. Calculating the uncertainty for the kinetic coefficient of friction was done using the same method mentioned for the static friction coefficients.

The calculations yielded an average coefficient of static friction of 0.650 for the large side of the block, and an average coefficient of static friction of 0.480 for the small side of the block as shown in **Table 1**. The standard errors of the means are 0.0328 and 0.00846 respectively, which are relatively low and show consistency between trials. These results deviate slightly from established physical theory since the intervals produced from the errors of the small and large area coefficients do not overlap with each other. This means that it can be confidently said that the coefficient of static friction of the large side is larger than the coefficient of static friction of the small area for this block. In theory, assuming that the two sides are made of the same material, the coefficients of static friction should be the same for both large and small sides. This discrepancy could be due to slight imperfections on the large side of the block, such as residue from a half-peeled sticker that was seen during the lab.

The coefficient of kinetic friction was calculated to be 0.421 for the large side of the block and 0.492 for the small side of the block. The standard errors of the means were 0.00716 and 0.00581 respectively. Although closer together than the static friction calculations, the intervals produced by the means and errors of the kinetic friction coefficients still do not overlap, which means that it can be confidently said that the two sides have different coefficients of kinetic friction. Just like the static friction coefficients, the kinetic friction coefficients also deviate from established physical theory since the coefficient of kinetic friction should not be dependent on the area of the surface, but only the material of the two surfaces in contact. Once again, this may be due to slight imperfections on either side of the block which may make it rougher or smoother and therefore alter the coefficient of friction.

Table 1: Coefficient of Static Friction

Trial	**Large Area**	**Small Area**
1	0.611	0.528
2	0.584	0.446
3	0.583	0.481
4	0.623	0.487
5	0.732	0.452
6	0.882	0.461
7	0.596	0.481
8	0.598	0.483
9	0.646	0.502
Avg	0.650 ± 0.0328	0.480 ± 0.00846

Table 2: Coefficient of Kinetic Friction

Trial	**Large Area**	**Small Area**
1	0.456	0.505
2	0.405	0.478
3	0.398	0.478
4	0.402	0.477
5	0.406	0.505
6	0.434	0.488
7	0.449	0.471
8	0.411	0.506
9	0.424	0.521
Avg	0.421 ± 0.00716	0.492 ± 0.00581

4. Conclusions

In conclusion, the purpose of this lab was to find the static and kinetic coefficients of friction between a wooden block and a metal ramp. The coefficient of static friction was determined by gradually increasing the angle of the plane until the block started to slide. The horizontal and vertical distances were then measured at the point where the block began to move. The coefficient of kinetic friction was determined by fixing the angle of the plane and sliding the block down the ramp, then finding the angle of the plane and the acceleration of the block relative to the plane. The calculations for the coefficients of friction were repeated for multiple trials on both the large and small sides of the block. Results deviated slightly from theoretical expectations, however, the consistency between trials may point to faults in the lab equipment. Overall, the experiment was successful in determining the coefficients of friction, and the results can be used to further understand the physics of frictional forces.