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**Lab 5: Newton’s Laws: Static and Kinetic Friction**

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PHYS 261 – 005

With:

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**Objective**

The objective of this lab was to familiarize ourselves with the concepts of static and kinetic frictional forces and the difference between the two. We would learn how different coefficients of friction affect the tendency of objects to move when force is applied.

**Theory**

The theory being tested is that objects with a force applied to them across the surface of another object experience a frictional force in the opposite direction. The magnitude of the frictional force is dependent on the magnitude of the normal force *N* acting on the object, and the coefficient of friction *µ* acting between the two surfaces. The two kinds of frictional forces are static and kinetic friction. When the force is applied to the object, the object will completely resist motion if the product frictional force is less than the maximum static frictional force given by the force *N* and the static coefficient of friction *µs*. Meaning, the object will not move so long as the inequality

Eq. 5-1

is true. If Eq. 5-1 is false, then the block will begin to slide with a net force equivalent to the acting force minus the kinetic frictional force. The kinetic frictional force *fk* is given using a new coefficient of friction *µk*.

Eq. 5-2

Because the frictional force is a ratio between the coefficient of friction and the normal force on the object, the static coefficient of friction for an object can be found inversely by

Eq. 5-3

However, because kinetic friction requires the object to be in motion, this doesn’t work quite the same way, so to find the coefficient of static friction in a rope (or string) and pulley system with a hanging mass, we use an equation given the mass of the hanging object *m* and the mass of the object experiencing friction *M*

Eq. 5-4

**Procedure**

**Procedure A**

Procedure A was all about finding kinetic coefficients of friction experimentally. We were given a block with a wood side and a felt side, and the purpose was to determine the kinetic coefficient for both sides. To do so, we used the rope-and-pulley system mentioned above. However, we needed acceleration to use Eq. 5-4. This value was reached using a LabPro extension called a photogate that would determine that velocity of the rope-and-pulley system based on the rate at which the spokes of the pulley passed in front of it. This setup was trialed 5 times, each at different weights for the block and the hanging mass, for each side of the block to get averages for the coefficients of friction to account for the error in the apparatus.

**Procedure B**

Procedure B was about finding the static coefficients of friction for the sides of the block. Doing this was simple: the block would be placed near and end of the track that was previously used in procedure A while that end was slowly lifted until the maximum static force was reached, at which point the current height of the lifted end of the track would be recorded, and from that and the length of the track, the static coefficients would be determined. This procedure was also carried out 5 times for each side of the block to create room for error.

**Data**

Below are the measurements taken for **Procedure A** and the resulting theoretical kinetic friction coefficients.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Wooden Side |  |  |  |  |  |  |
|  | M (kg) | m (kg) | a (m/s2) | Mg | mg-(M+m)a | µk |
| 1 | 0.1402 | 0.1 | 0.3052 | 1.374913 | 0.90737096 | 0.659948 |
| 2 | 0.1902 | 0.15 | 1.332 | 1.865253 | 1.0178736 | 0.545703 |
| 3 | 0.2402 | 0.2 | 1.446 | 2.355593 | 1.3248308 | 0.562419 |
| 4 | 0.2902 | 0.25 | 1.61 | 2.845933 | 1.581978 | 0.555873 |
| 5 | 0.3402 | 0.3 | 1.639 | 3.336273 | 1.8927522 | 0.567325 |
|  |  |  |  |  |  |  |
| Felt Side |  |  |  |  |  |  |
|  | M (kg) | m (kg) | a (m/s2) | Mg | mg-(M+m)a | µk |
| 1 | 0.1402 | 0.1 | 1.812 | 1.374913 | 0.5454376 | 0.396707 |
| 2 | 0.1902 | 0.15 | 2.111 | 1.865253 | 0.7528578 | 0.403622 |
| 3 | 0.2402 | 0.2 | 2.322 | 2.355593 | 0.9392156 | 0.398717 |
| 4 | 0.2902 | 0.25 | 2.461 | 2.845933 | 1.1222678 | 0.394341 |
| 5 | 0.3402 | 0.3 | 2.533 | 3.336273 | 1.3204134 | 0.395775 |

**Table 5-1.** The table of measurements and calculated kinetic coefficients from all of the runs in Procedure A.

Next are the measurements taken for **Procedure B** and the theoretical static coefficients of friction derived therefrom.

|  |  |  |  |
| --- | --- | --- | --- |
| Length of Track (cm) | | 107 |  |
| WOOD |  |  |  |
| # | H (cm) | θ (°) | µs |
| 1 | 75.5 | 44.8786421 | 0.995773 |
| 2 | 66 | 38.084461 | 0.783662 |
| 3 | 73.6 | 43.4601947 | 0.947645 |
| 4 | 86.8 | 54.214806 | 1.38729 |
| 5 | 58 | 32.8237147 | 0.645042 |
|  |  |  |  |
| FELT |  |  |  |
| # | H (cm) | θ (°) | µs |
| 1 | 63.5 | 36.4027803 | 0.737338 |
| 2 | 64 | 36.736146 | 0.746359 |
| 3 | 66.4 | 38.3570948 | 0.791372 |
| 4 | 64.2 | 36.8698976 | 0.75 |
| 5 | 63.8 | 36.6026269 | 0.742737 |

**Table 5-2.** The table of measurements and calculated static coefficients from all the runs in Procedure B.

**Analysis**

**Procedure A**

The kinetic coefficients of friction were calculated for each run using an equation derived from Newton’s second law of motion under the pretense that the tension from the hanging mass will always provide the sideways force on the block. Using Eq. 5-2 as a starting point, we have

Which can be inverted to

Now, because the track is flat, we know the normal force to be equal to

We also know the equation for net force on an object in motion

Which can be inverted to

Now, because the track is flat, and we are using a rope-and-pulley system, we know the only horizontal force acting on the block is the tension from the string, thus

And we know that the net force can be found by adding the net forces on the system components

Which can be simplified to

Then substituting Fx and Fnet, we find that

Which we then substitute, along with N, to arrive to the conclusion

This was how we arrived at the theoretical coefficients of kinetic friction for each trial. Taking all of the experimental coefficients into account, the statistics on the values are as follows.

|  |  |
| --- | --- |
| Wood µk average | 0.578254 |
| σwood | 0.04638 |
| Felt µk average | 0.397832 |
| σfelt | 0.003605 |

We can plot the results of Table 5-1 on scatter plots to get visual representations of the kinetic coefficients.

**Figure 5-1.** Regressed scatter plot and trendline for the trial data on the wood side of the block.

**Figure 5-2.** The same data, but for the felt side of the block.

The standard deviations on the regressed trendlines are σWood = 0.06473969 and σFelt = 0.007412752.

The results for the kinetic coefficient on both the wood and the felt sides barely agree within one deviation, if using the regression deviation, but they make it.

**Procedure B**

Given Eq. 5-3, simple trigonometry allows us to derive an easy method for calculating the coefficient of static friction. The trigonometric ratio tangent can be expressed as

If we consider that the height at which the block starts to slide is the *y* in our triangle, and the length of the track is the x, then

Because it gives us the angle at which the block starts to move, and

These can be substituted into Eq. 5-3 to give us the equation

Which simplifies to

Eq. 5-5

Using this identity, and the measurements taken over the trials of Procedure B, we found the coefficients seen in Table 5-2. Analysis of the data shows the following results:

|  |  |
| --- | --- |
| Average µs Wood | 0.951882 |
| σwood | 0.280166 |
| Average µs Felt | 0.753561 |
| σfelt | 0.021648 |

**Overview**

Normally, the µs is greater than µk. Looking at the results of the deviations for both Procedure A and B, this trend seems to hold up.

**Conclusions**

We have performed an analysis of the experimental results for the kinetic and static coefficients of friction of two different materials on a track. Procedure A’s data was very precise as evident by the low deviation in on both the data and the trendline regression. Procedure B’s data was not quite as reliable, because of the almost impossible friction constant that we measured when taking the average of all the experimental static coefficients for the wood side. The reason for this is unknown, but the block simply would not let go of the track until it was getting near perpendicular. This caused a significant error margin in the measurements for that half of Procedure B, but the felt half ran as expected with a negligible margin of error. All the relationships that we expected to see in this lab were fulfilled except for the funkiness in Procedure B, and all the data and calculations followed the reasoning of the theory very well. Thus, this lab is good evidence for the theory stated, and the objective of the lab has been achieved by this group.