Forces of Friction

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The contact of two surfaces causes frictional forces that act on the motion of the experimented object. In this experiment, the differences between static and kinetic friction were analyzed using three different methods for comparison. Throughout all of the trials, it was found that the coefficient of static friction and the force of static friction were consistently higher than that of the kinetic friction taking place. The first method was found to be the most accurate when comparing static and kinetic friction. The final coefficients for each value based on plotting them against the normal force and taking the slope of that linear relationship had a percent difference of 1.14%. Since the angle of the surface for the normal force was flat, these values theoretically would have the slightest of difference. A 13.6% difference was calculated between the coefficients for kinetic friction in Method 1 and Method 3. Since the hanging mass was added for the third method, it would be expected for a larger kinetic friction, however that was not the case based on the overall experiment.

I. INTRODUCTION

The force of friction vector acts in the opposite direction of the motion of the object causing the friction. Any time there is contact made between an object and a surface, the process of gravity pushing downward on the object causing a friction connection on the surface where that object makes contact. The normal force is what balances out the force made my gravity on the object, therefore contact is never lost in between the object and the surface. The friction is proportional to the normal force of the surface plane, thus a linear relationship between the friction and normal forces can be plotted. Before Newton's force laws came about, Leonardo Da Vinci and later Guillaume Amontons had worked on the theoretical laws for friction that are put to test in this experiment. It was discovered by those scientists that friction is completely independent to the size of whatever surface is making contact. With that being known, the coefficient of the friction is independent of the mass of the object being moved.

II. THEORY AND METHODS

Friction is the resistance to motion along a surface. The three methods used to examine how the frictional forces act on a surface included; sliding various masses at an attempted constant velocity, increasing the angle of the surface in which the normal force acted on, and applying the forces of a hanging mass to have a constant acceleration and increasing velocity on the mass that the friction was being analyzed from. The Data Studio application on the lab computer was wired to a force probe on the object in contact with the surface as well as a motion sensor at the opposing end from the object's directional velocity. The motion sensor charted the carts position and velocity graphs over time, while the force probe took in data for the force being applied (after calibrating the sensor, or 'zeroing' the force scale out) to the object at the same time instances that the position and velocity along the surface were being plotted. Prior to each trial for each separate method, the force probe had to 'tare' itself to again by the press of a button to calibrate it for a new trial to be performed.

The mass of the object in contact with the surface was varied for the first method for each individual trial. A table was made using Microsoft Excel to collect orderly data including; total mass on the object, the normal force (calculated using Equation 2 below), static friction (final point on force vs. time plot that involved a stationary position, and the kinetic friction (averaged for constant velocity time period) with standard deviation for kinetic friction (calculated by Data Studio).

$$F_N = F_g cos\theta \qquad (2)$$

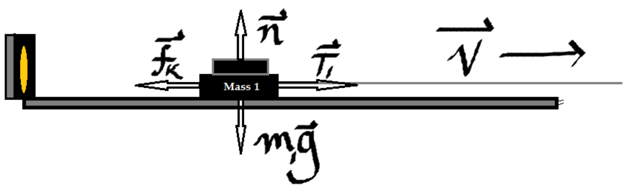

Figure 1: The first method looked at both static and kinetic friction at a constant velocity pulling by a consistent lab member. This figure shows the force configuration after the object began moving along the surface.

Data for the second method (finding angle of surface incline before kinetic friction takes place) was compiled by making a table of the angle measurement taken after resetting to a flat surface for each trial (Table 1 on next page). These measurements could find the coefficient of static friction (using Equation 4 below) and its standard deviation.

$$\mu_s = \frac{sin\theta}{cos\theta} = tan\theta \qquad (4)$$

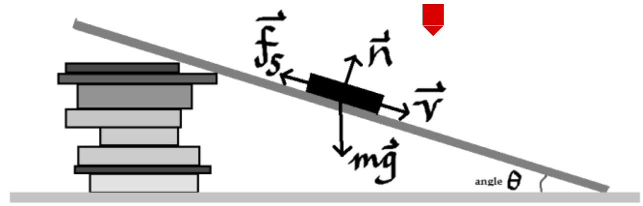

Figure 2: To increase the surface incline angle, lab group members stacked up various textbooks and folders while closely watching for the threshold of static friction to transform into kinetic friction. The angle of incline was then taken for data calculations.

The final method was setup as Figure 3 shows, with a constant hanging mass (0.20kg) pulling the object (.947kg) along the surface. For data collection, Data Studio plotted the linear velocity curve and the force vs. time curve (showing kinetic friction). By taking the slope of the velocity, constant acceleration could be found, and used to find the coefficient of kinetic friction with Equation 6 below. This would then be compared the value found using Method 1.

$$\mu_k = \frac{m_2\vec{g} - (m_1+m_2)\vec{a}}{m_1\vec{g}} \qquad (6)$$

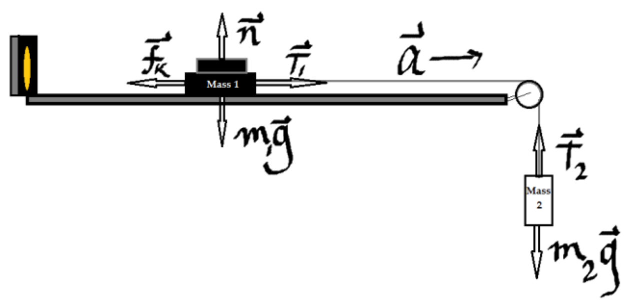

Figure 3: Set up for the third method consisted of modifying the Atwood system with two masses for the friction experiment. This one was designed to look at kinetic friction and its coefficient.

III. Discussion of Results

The first method of finding values for friction (both static and kinetic) left much room for human error, since it was up to a lab member to pull the object along the surface at a constant velocity (seen in Figure 4).

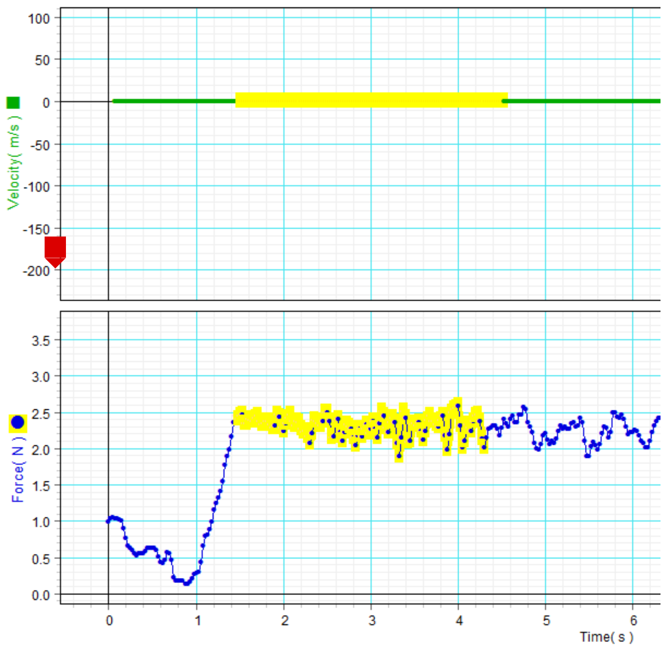

Figure 4: The above figure is from the first method's second run. The green plot represents a constant velocity over time (extremely zoomed out of scale in meters). The same set of points were taken to analyze frictional forces (blue plot).

By plotting both the static and kinetic friction points against the normal force that was calculated, the linear proportion can be viewed. Thus, the slopes of the line of fit reveal the coefficient of static and kinetic friction (Figures 5 and 6). These coefficient values will later be compared to those found using the second and third methods of this experiment.

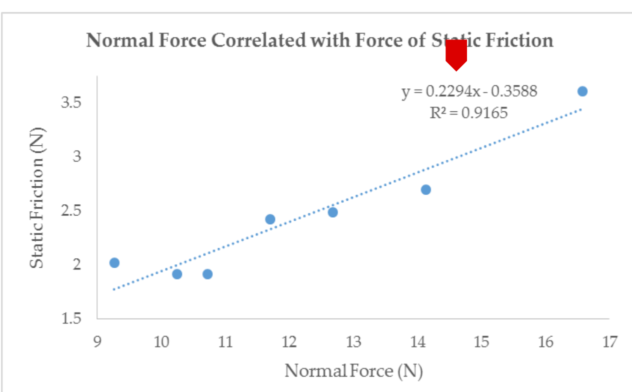

Figure 5: Static friction and the normal force from the surface show a linear relationship with the slope of the line of best fit to be the coefficient of static friction. This experimentally came out to be slightly greater than that of kinetic friction.

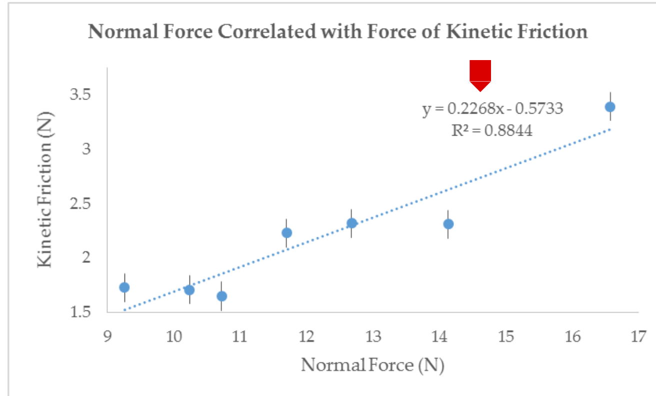

Figure 6: The linear relationship between kinetic friction and normal forces has a slope that determines that coefficient of kinetic friction. The R^2 value is further off from 1 than expected in an experiment since it was difficult reading the resulting DataStudio graphs.

The second method of looking at static friction took the coefficient of static friction based on the measured angle of incline and compared it to the static friction values found by using the first method. There was an extreme percent difference of the two values found using both methods, and therefore it was assumed that in Method 1 it was very difficult to find the exact point that static friction broke due to the Data Studio graphs being difficult to read. This method of finding the angle would be the more accurate method for finding the coefficient of static friction (the least human error, more consistent systematic error). More trials would not necessarily make the second method better than it is with the current results because the angle uncertainty is so large considering the scale of the angle being measured. More trials by use of the first method would double the data points to plot and would affect the slope of the line in seen in Figure 5, making it more accurate. Both cannot be made much more precise since there are significant sources of error involved.

Table 1: Measurements for angle of the surface for each trial were taken to help determine at what instance the static friction reached the threshold just before kinetic movement began on the object.

Run	Angle (degrees)
1	10
2	9.9
3	10
4	9.8
5	10

For looking at the kinetic friction force, the third method has less room for human error. Therefore, this is the method for most accuracy. In Figure 7, a standard deviation of 0.02 of the continuous friction force was taken from a certain time period of data across the position, velocity, and force plots from Data Studio. The coefficient of kinetic friction would have a greater value in the third method rather than the first, since the inertia is greater (due to the added hanging mass), and acceleration is constant in the opposite direction of the kinetic friction force. Experimentally, this proved to be true as well. The coefficient of kinetic friction was .227 for the first method (smaller inertia), whereas it was .198 for the third method. The difference of the kinetic friction coefficients is calculated to be 13.36%. Based on standard deviation (used for Method 1) and error propagation (used for Method 3), the third method also proves to be the most precise method to use when performing kinetic friction experiments.

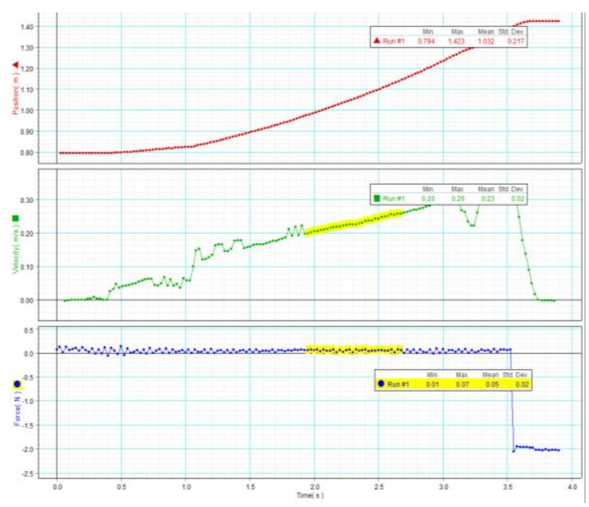

Figure 7: These graphs show the position (red) of the frictional object, the velocity of the object that increases (green), and the kinetic friction force plot (blue) over the same time period.

Sources of error came about in the three different methods that were attempted to be avoided as much as possible. When doing the first experiment, a lab group member considered it difficult to pull the massed object with a *constant* velocity along the surface. Therefore, to avoid this harming the data being collected, a best fit of the data points was taken from the velocity curve, and those same instances were then taken from the force plot over the same time period. The second method that involved finding the angle at which static friction was at the threshold of becoming kinetic friction was difficult to get varied results. The angle uncertainty (0.1 degree) based on the measurement device was too large to detect much difference in the frictional changes over the five trials taken. Also, 'eyeballing' the object for the exact point in which kinetic friction was applied and static friction ceased to exist was not the most accurate way this method could have been done.

IV. References

1. Schumacher, Donald, Prof. "Force of Friction" Physics Lab Packet. ERAU, Daytona Beach, FL. 10 March. 2015. Reading.
2. [redacted] Physics Lab #8. 10 March. 2015. Raw Data. ERAU, Daytona Beach, FL.
3. "History." *Friction: History*. Davidson University, n.d. Web. 20 Mar. 2015.
4. N. "Static and Dynamic Friction." Lab 4: Static and Dynamic Friction (n.d.): 1-3. Physics Dept. Clark University. Web. 20 Mar. 2015.
5. F. PHY 251 Lab 5 – Friction (n.d.): Mississippi College. Web. 20 Mar. 2015. <www.mc.edu>.

V. CALCULATIONS

Method 1: Static & Kinetic Friction

$$F_{fric} = F_{s,k} = \mu_{s,k} F_N \qquad (1)$$

$$F_N = F_g cos\theta \qquad (2)$$

$$\theta = 0° \ (flat\ surface) \qquad (3)$$

Method 2: Static Friction

$$\mu_s = \frac{sin\theta}{cos\theta} = tan\theta \qquad (4)$$

Method 3: Kinetic Friction

$$\mu_k \vec{g} = \vec{a} \qquad (5)$$

$$\mu_k = \frac{m_2\vec{g} - (m_1 + m_2)\vec{a}}{m_1\vec{g}} \qquad (6)$$

Error Propagation for Kinetic Friction

$$\delta_{\mu_k} = \sqrt{\left(\frac{\partial \mu_k}{\partial m_1}(\delta_{m_1})\right)^2 + \left(\frac{\partial \mu_k}{\partial m_2}(\delta_{m_2})\right)^2 + \left(\frac{\partial \mu_k}{\partial a}(\delta_a)\right)^2}$$

$$\delta_{\mu_k} = .00347$$

VI. Plot Data

Table 2:
Method 1 involved using a lab member to pull the massed object along the flat surface at a constant velocity.

Method 1: Sliding Friction Equalities								
Run #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Avg**
Total Mass (kg)	0.9466	1.444	1.1953	1.0463	1.295	1.0958	1.6927	N/A
Angle (degrees)	0	0	0	0	0	0	0	0
Normal Force (N)	9.26721	14.1368	11.702	10.2433	12.6781	10.7279	16.5715	12.19
Static Friction (N)	2.02	2.7	2.42	1.91	2.49	1.91	3.61	2.437
Kinetic Friction (N)	1.73	2.31	2.23	1.71	2.32	1.65	3.39	2.191
$\sigma(F_k)$	0.08	0.13	0.17	0.13	0.13	0.15	0.14	0.133

Table 3:
Method 2 found the threshold for the static friction just before it escalated into kinetic friction force based on the incline angle.

Method 2: Angle of Friction						
Run #	**1**	**2**	**3**	**4**	**5**	**Avg**
Total Mass (kg)	0.9466	0.9466	0.9466	0.9466	0.9466	N/A
Angle (degrees)	10	9.9	10	9.8	10	9.94
μ_s	0.64836	0.51455	0.64836	0.39388	0.64836	0.5707
$\sigma(F_s)$						0.10248

Table 4:
The third method found the coefficient of kinetic friction by applying a hanging mass to the other end of pulley system.

Method 3: Modified Atwood with Friction								
Run #	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Avg**
Total Mass 1 (kg)	0.947	0.947	0.947	0.947	0.947	0.947	0.947	N/A
Hanging Mass 2 (kg)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	N/A
Acceleration (m/s^2)	0.116	0.12	0.101	0.1	0.092	0.098	0.109	0.105
μ_k	0.197	0.196	0.198	0.198	0.199	0.199	0.197	0.198