Experiment 5: Friction and the Inclined Plane

PHYS LAB 1730

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1 Abstract

The objective of this experiment was to experimentally determine the coefficient of friction between two surfaces using two different methods, and find out what factors lead to the determination of such friction coefficient. Some of the factors included mass of the object, angle of elevation, and the surface area of the object in contact with the plane. The two methods used included adding weights to a pulley until the tension force from the pulley overcame the static friction of a weighted block on a flat surface, and adding weights to a pulley until it overcame the static friction of an unweighted block on an inclined surface. Throughout both of these methods, the factors mentioned above were all varied to ensure consistent results.

In our results, we found that the experimental values determined for the coefficient of kinetic friction were mostly consistent with one another. There were small lapses in between the experimental values, due to factors such as human error in the stopwatch timing, judgmental errors in determining the amount of weight needed to overcome the static friction force, and inconsistencies between the surfaces and blocks themselves. This ultimately means that factors such as mass, angle, and surface area ultimately have a negligible effect on the kinetic friction coefficient.

2 Introduction

The coefficient of kinetic friction is a constant that depends on the two surfaces that it relates. Friction is a force that acts against the movement of an object on a surface. Two major types of friction forces include static friction and kinetic friction. Static friction is the force of friction when an object is at rest, and kinetic friction is the force of friction when an object is in motion. The force of static friction is always larger than the force of kinetic friction, which is why the experiment involves giving the block a "push" to overcome the force of static friction and set the object into motion, allowing for the measurement of the coefficient of kinetic friction. The coefficient of kinetic friction is simply the the ratio of the force of kinetic energy to the normal force. Since it compares two forces whose units are both in Newtons, it is dimensionless. It is given by the equation

$$\mu_k = \frac{F_k}{N}, \tag{1}$$

where μ_k is the coefficient of kinetic friction, N is the normal force, and F_k is the force of kinetic friction. To see where this equation comes from, consider the equation for the force of kinetic friction, given by

$$F_k = \mu_k N. \tag{2}$$

Right multiplying by the multiplicative inverse of N will yield $\mu_k = \frac{F_k}{N}$. Similarly, consider the equation for the force of static friction, given by

$$F_s = \mu_s N, \tag{3}$$

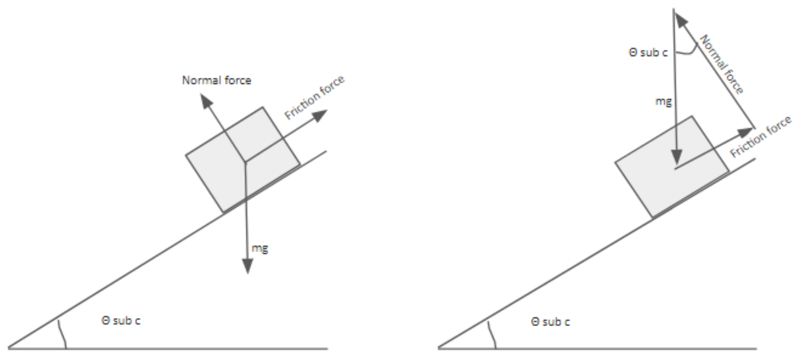

Figure 1: The free body diagram.

where F_s is the force of static friction, μ_s is the coefficient of static friction, and N is the normal force. Once again, right multiplication by the inverse of N will yield

$$\mu_s = \frac{F_s}{N}, \tag{4}$$

which is the equation for the coefficient of static friction. In the case of an inclined plane, the equations for the normal force and the kinetic friction can be given by

$$F_k = mg\sin(\theta_c) \tag{5}$$

and

$$N = mg\sin(\theta_c), \tag{6}$$

where m is the mass of the object in kg, g is the gravitational constant in $\frac{cm}{s}$, and θ_c is the angle between the ground and the inclined plane. The gravitational force is measured in $\frac{cm}{s}$ because all forces in this experiment were calculated in dynes, where $1\,\mathrm{dyn} = 1\,\frac{g \cdot cm}{s^2}$. Therefore, $g = 980\,\frac{cm}{s}$. Since $\mu_k = \frac{F_k}{N}$, we simply divide equation 5 by equation 6 to obtain

$$\mu_k = \frac{F_k}{N} = \frac{mg\sin(\theta_c)}{mg\sin(\theta_c)} = \tan(\theta_c). \tag{7}$$

These equations can be obtained from the free body diagram as shown in Figure 1. By the right triangle in the right half of Figure 1, we can see that $\sin(\theta_k) = \frac{F_k}{mg}$ and $\cos(\theta_k) = \frac{N}{mg}$. We can easily rearrange these expressions to obtain equations 5 and 6.

3 Apparatus

The apparatus used are listed below:

- Adjustable inclined plane
- Wooden block with holes on side and top
- Varying weights of grams (including 500g and 1kg)
- Hanger for the weights
- String with a length of one meter
- Meterstick.

The purpose of the experiment was to measure the friction coefficient between the materials of the surfaces of the block and the inclined plane, making them essential apparatus to the experiment. The varying weights of grams were attached to the hanger to obtain a precise weight at which the block would begin to slide toward the edge on the inclined plane. The 500g and 1kg gram weights in particular were placed in the holes of the wooden block to increase its mass. The string was used to connect the block and the weight hanger. Finally, the meterstick was used in measuring the heights and lengths of the plane.

4 Experimental Procedure

Part A

1. Use a triple beam balance to obtain the mass of the block. Use such mass to solve for the weight in dynes, and record the resulting data.
2. Lay the block down flat on the incline plane with an angle of $0°$. Adjust the plane so that the pulley extends beyond the table, allowing for the weight hanger to fall below the table.
3. Set the height of the pulley and the elevation of the block equal to each other.
4. Slowly add weights to the weight hanger in small increments, testing to see if the weight is enough to overcome the force of kinetic friction each time by giving the block a small push to overcome the force of static friction.
5. Record the masses of the weights (including the weight hanger) that overcame the force of kinetic friction successfully.
6. Add a 500g weight to the block itself. The block should have a hole that fits the 500g weight on both its side and top. Repeat steps 2-5.
7. Remove the 500g weight and add the 1kg weight. Repeat steps 2-5.

8. Lay the block on its side, decreasing the surface area in contact with the plane, and repeat steps 2-7.

9. Raise the incline plane to an angle of $15°$. Lay the block down flat on the place, and perform step 4 again.

10. Repeat step 9 twice, raising the plane to angles of $30°$ and $45°$ respectively.

Part B

1. Lay the block down flat on the incline plane with a starting angle of $0°$. Slowly adjust the angle of the incline plane upward until the block begins to slide down the plane by itself after having received a small push to overcome the force of static friction.

2. Record the exact angle at which the block was able to successfully overcome the force of kinetic friction. Using the meterstick, obtain the measurements for the height and base (or length) of the plane, and record.

3. Repeat steps 1 and 2 twice, adding a 500g and 1kg weight to the block each time, respectively. Remove the 500g weight before adding the 1kg weight on the third trial.

5 Data

Table 1: Data obtained from steps 1-8 of part A.

Object moved	Weight W(dynes)	Side Used	Angle (θ)	Pulling Force F(dynes)	Coefficient of Friction
Block only	$1.92 \cdot 10^5$	Wide	0	$4.90 \cdot 10^4$	0.255
Block+500g	$6.82 \cdot 10^5$	Wide	0	$1.62 \cdot 10^5$	0.251
Block+1kg	$1.17 \cdot 10^6$	Wide	0	$2.99 \cdot 10^5$	0.256
Block only	$1.92 \cdot 10^5$	Narrow	0	$5.39 \cdot 10^4$	0.280
Block+500g	$6.82 \cdot 10^5$	Narrow	0	$1.79 \cdot 10^5$	0.263
Block+1kg	$1.17 \cdot 10^6$	Narrow	0	$3.04 \cdot 10^5$	0.260

Table 2: Data obtained from steps 9 and 10 of part A. Note that N = Normal Force = $W\cos\theta$, Parallel Force = $W\sin\theta$, Frictional Force = f = $F - W\sin\theta$, and the Coefficient of Friction = $\mu_k = \frac{f}{N}$.

Object moved	Pulling Force F(dynes)	Angle (θ)	Normal Force	Parallel Force	Frictional Force	Coefficient of Friction
Block only	$9.99 \cdot 10^4$	15°	$1.86 \cdot 10^5$	$4.98 \cdot 10^4$	$5.01 \cdot 10^4$	0.269
Block only	$1.42 \cdot 10^5$	30°	$1.67 \cdot 10^5$	$9.62 \cdot 10^4$	$4.59 \cdot 10^4$	0.276
Block only	$1.68 \cdot 10^5$	45°	$1.36 \cdot 10^5$	$1.30 \cdot 10^5$	$3.16 \cdot 10^4$	0.232

Table 3: Data obtained from part B of the experiment. Note that h denotes height of the inclined plane and b denotes the length of the base of the inclined plane. Also note that μ_k can be calculated two ways, with the respective method for calculating μ_k listed as the column title.

Object moved	Weight W(dynes)	Angle (θ)	h (cm)	b (cm)	$\mu_k = \frac{h}{b}$	$\mu_k = \tan\theta$
Block only	$1.92 \cdot 10^5$	13.5°	16.7	69.8	0.239	0.240
Block +500g	$6.82 \cdot 10^5$	13.5°	16.7	69.8	0.239	0.240
Block +1kg	$1.17 \cdot 10^6$	13.5°	16.7	69.8	0.239	0.240

6 Calculations and Graphs

Part A

Figure 2 details the plot between the coefficient of kinetic friction (μ_k) and the weight in dynes. A simple linear regression gives a best fit line of

$$y = (-9.93 \cdot 10^{-9})x + 0.271, \tag{8}$$

with

$$r^2 = 0.194. \tag{9}$$

The slope of the line of best fit is negligibly small, yielding a linear equation that almost seems constant. Therefore, we can conclude that the weight in dynes has a negligible effect on the coefficient of kinetic friction. Examining Figure 2 closely, there almost appear to be two sets of points making one graph, due to the fact that both the plots for weights on the wide side and the narrow side are plotted together in Figure 2. Refer to the table below for a comparison of

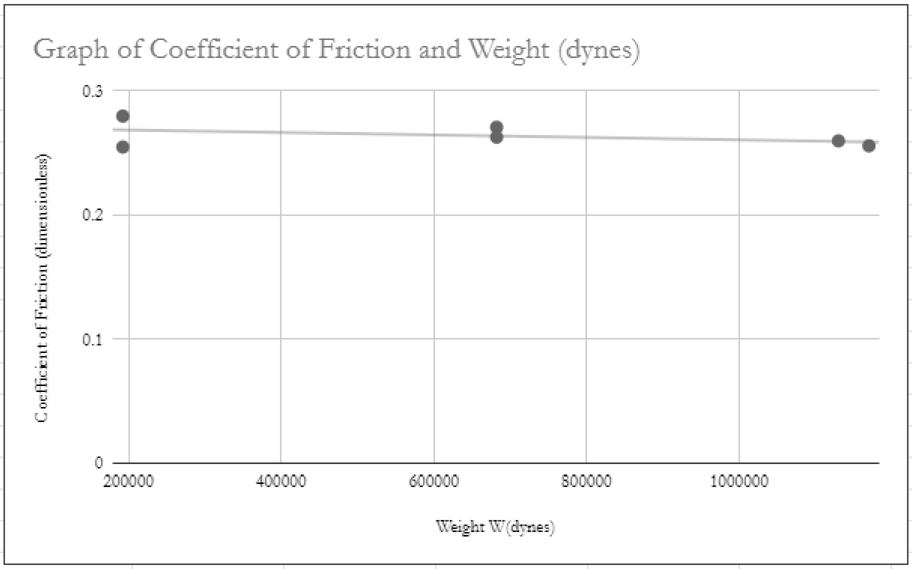

Figure 2: A plot between μ_k and W(dynes).

the percent differences [1] between the coefficient of kinetic friction determined by the wide side and the narrow side making contact with the inclined plane.

	μ_k (Wide side)	μ_k (Narrow side)	Percent difference
Block only	0.255	0.280	9.35%
Block + 500g	0.251	0.263	4.67%
Block + 1kg	0.256	0.260	1.55%

In the table above, the percent differences between the values obtained through placing the block on its wide side and placing the block on its narrow side are extremely low. Therefore, we can conclude that both weight and surface area are negligible in the calculation of the coefficient of kinetic friction, due to the extremely small coefficient of the linear line of best fit generated by linear regression and the extremely low percent differences obtained by comparing the values of μ_k for the wide and narrow sides of the block.

Let us turn our attention to Figure 3. This details the plot between the angle of incline of the inclined plane, θ, and the coefficient of kinetic friction, μ_k. In this graph, μ_k was measured with three different values of θ, the values being $15°, 30°$, and $45°$ respectively. Once again performing a simple linear regression

[1] The percent difference between two values, say x_1 and x_2, is given by the formula

$$\frac{\mid x_1 - x_2 \mid}{avg(x_1, x_2)} \cdot 100\%, \tag{10}$$

where $avg(x_1, x_2) = \frac{x_1+x_2}{2}$.

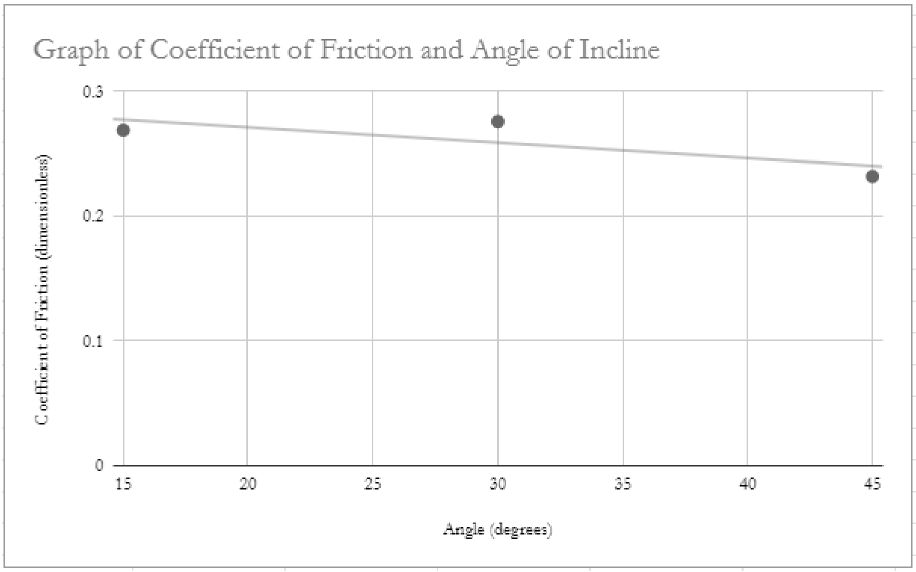

Figure 3: A plot between μ_k and θ (angle of incline).

on Figure 3, we obtain

$$y = (-1.23 \cdot 10^{-3})x + 0.296 \tag{11}$$

as the line of best fit, and

$$r^2 = 0.612. \tag{12}$$

Once again the linear coefficient of the line of best fit is negligibly small, and we can safely conclude that θ does not have any substantial impact on μ_k.

Part B

In this part of the experiment, we measured the angle at which the block (at varying weights) would begin to slide down the inclined plane. Since we obtained the exact same values of theta ($\theta = 13.5°$) for all three weights of the block (no weight, +500g, +1kg), μ_k almost didn't change at all with the varying weights. We present the percent differences of μ_k calculated two ways below:

	$\mu_k = \frac{h}{b}$	$\mu_k = \tan\theta$	Percent difference
Block only	0.239	0.240	0.42%
Block + 500g	0.239	0.240	0.42%
Block + 1kg	0.239	0.240	0.42%,

where the first value of μ_k was calculated by dividing h, the height in centimeters of the inclined plane by b, the length of the base of the inclined plane in centimeters. The second value of μ_k was calculated by taking the tangent of the angle of incline of the inclined plane (θ). As can be seen by the astronomically low percent difference, the effect of the weight of the block on the coefficient of kinetic friction is truly negligible.

7 Discussion of Results and Error Analysis

The purpose of this experiment was to obtain the coefficient of kinetic friction between two surfaces, and measure the impact of various factors on the determination of such coefficient of kinetic friction. Since the value of r^2 was low for both linear regressions of Figure 2 and Figure 3, there doesn't appear to be much of a correlation between the weight of the object and the angle of incline of the inclined plane (θ) with the coefficient of kinetic friction (μ_k), respectively. On the topic of surface area, the percent difference between the values of μ_k obtained by using the wide and narrow sides of the block respectively were extremely small, leading to the conclusion that the amount of surface area of the object in contact with the inclined plane is not relevant to the value of the coefficient of kinetic friction either. Therefore, we can safely conclude that μ_k is independent of external factors such as weight, angle of incline, or surface area.

However, even though the percent differences were extremely low, there were still differences between the values calculated as the methods changed. Some reasons for this difference include the method of calculation, namely the difference between analytical and experimental methods of obtaining the value of μ_k. For example, consider the two methods for calculating μ_k in Part B, namely

$$\mu_k = \frac{h}{b} \tag{13}$$

and

$$\mu_k = \tan\theta \tag{14}$$

respectively. Equation 13 is more susceptible to measurement error since it requires taking the measurements of the height and base of the inclined plane, the measurements for which may be to the slightest degree inaccurate due to the fact that the meterstick's resolution is not high enough. On the other hand, Equation 14 only relies on the angle θ, which is still prone to error, but on a smaller scale, since only one variable depends on the resolution of the instrument used.

There were several other factors that may have led to the percent differences between the trials. The inclined plane was not completely even, leading to blocks sliding down with different masses depending on which part of the plane it was placed on. Judgmental lapses may have led to recording an inaccurate value for the weight required for the block to overcome the force of kinetic friction. For example, if the weight was recorded after pushing the block and prematurely stopping it due to the assumption that it had already overcome kinetic friction, it would be incorrect since the block was really only moving due to the fact that it was set in motion by the initial push.

8 Conclusion

Concluding the experiment, the outcome of the experiment strongly supports the theory proposed that the coefficient of kinetic friction is not dependent on outside factors. With the highest percent difference between different surface areas being 9.35% and the highest percent difference between the angles being 0.42%, it is clear that such factors are not important factors in determining μ_k.

Some ways that the error could be reduced include obtaining an instrument with a higher resolution to measure certain measurements such as the degree of θ and the values of h and b. Another way to reduce the error includes using newer surfaces for the incline plane and blocks, since the older ones tend to accumulate debris that impacts the friction between the two surfaces. Finally, using smaller increments to measure the exact gram weight at which the block overcomes the force of kinetic friction would lead to a more precise value for the weight, improving the accuracy of the experiment. Implementing these methods would surely reduce the percent difference, and perhaps even eliminate the difference altogether.