Phys 11A Lab - Eiteneer

# Friction Analysis Redux
# Project Report

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**Objective statement / purpose of the experiment -**

We are going to design, carry out, and analyze an experiment by which we determine a coefficient of kinetic friction between a wooden slab and a wooden block, as well as the amount of work done by friction in this experiment (both static and kinetic friction). We will try our best to increase the angle of the inclined plane until the static friction reaches the maximum possible static friction for the object to start sliding. We are going to learn more about frictional forces and the work done on objects this time.

**Theory/background and Experimental procedure –**

We will use a wooden slab or a wooden board for one of the inclines, with possible consideration for other materials to be used as the incline, like a cardboard ramp, or a metal ramp. Other objects that we can use apart from the wooden block to slide down the incline could be a brick, a book, and a small cardboard box filled with coins. Tools that we can use involve a measuring tape to help us determine the length of the inclines as well as stopwatches to determine how long it took a certain object to slide down the incline. We will also be using a protractor to measure the angle of the incline and use books, paper, boxes to increase the incline angle by stacking them under one end of the so-called "sliding ramp". We can also try measuring force with a spring scale. Some formulas that we can use, based on the previous lab, will be shown below:

Coefficient of Static Friction:

$$\mu_s = tan(\Theta)$$

Uncertainty of Coefficient of Static Friction:

$$\delta\theta \;=\; \frac{\pi}{180} radians$$

$$\delta\mu_s = (\frac{1}{cos(\theta)})^2 \delta\theta$$

Coefficient of Kinetic Friction:

$$\mu_k = tan(\Theta) - \frac{a}{gcos(\theta)}$$

Uncertainty of Coefficient of Kinetic Friction:

$$\delta\theta \;=\; \frac{\pi}{180} radians$$

$$\delta\mu_k = (sec^2\theta + \frac{atan(\theta)}{gcos(\theta)})\delta\theta$$

Acceleration, which can be determined by rearranging the distance formula we were given:

$d = \frac{1}{2}at^2$ => $a = \frac{2d}{t^2}$

Uncertainty in Acceleration:

$$a = \frac{2d}{t^2}$$

$$\frac{\partial a}{\partial d} = \frac{2}{t^2} \qquad \frac{\partial a}{\partial t} = \frac{-4d}{t^3}$$

$$\boxed{\delta a = \sqrt{\left(\frac{\partial a}{\partial d}\delta d\right)^2 + \left(\frac{\partial a}{\partial t}\delta t\right)^2}}$$

*We couldn't type that one symbol for some odd reason, so we wrote it.

Force:

Force = Mass * Acceleration

Work:

Work = Force * Distance

Work (With regards to force of static friction):

Work = $f_s * Distance$
$f_{s,max}$ = $\mu_s n$, where n = mass * gravity
$f_{s,max}$ = $\mu_s mg$
Work = $\mu_s * mass * gravity * distance$

Work (With regards to force of kinetic friction):

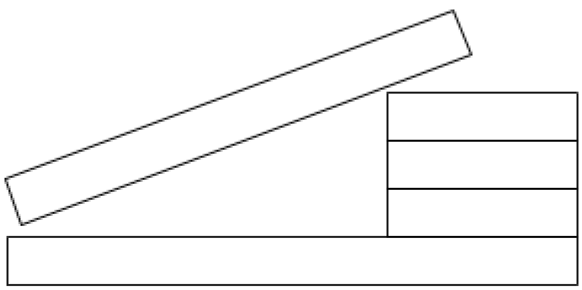
Work = $f_k * Distance$
$f_k$ = $\mu_k n$, where n = mass * gravity
$f_k$ = $\mu_k mg$
Work = $\mu_k * mass * gravity * distance$

Work (On an inclined plane):
W = F * $cos\theta$ * change in x

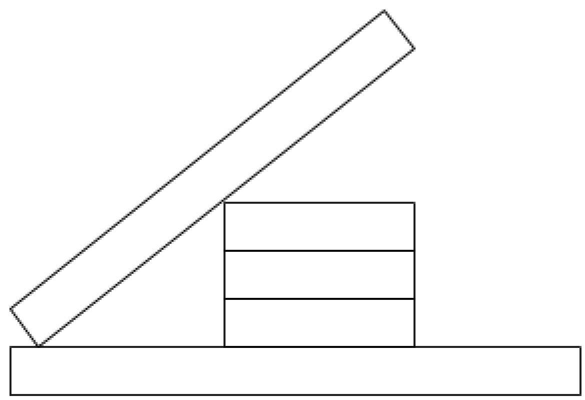
Friction (On an inclined plane):
$F_f = \mu n$
$F_f = \mu * m * g * cos(\theta)$

*And some other formulas if needed. We will know what we need when we get to it.

Some reference pictures below:



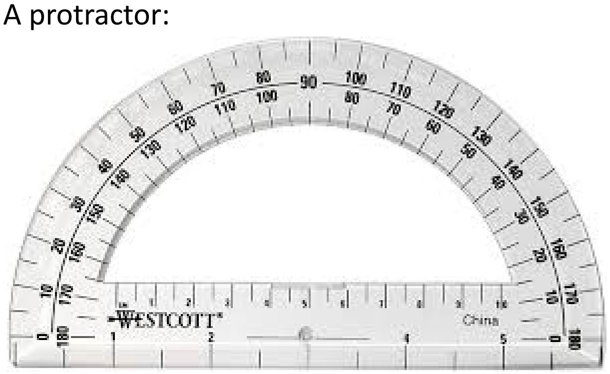
We will be using material like books and bricks to lift our incline.



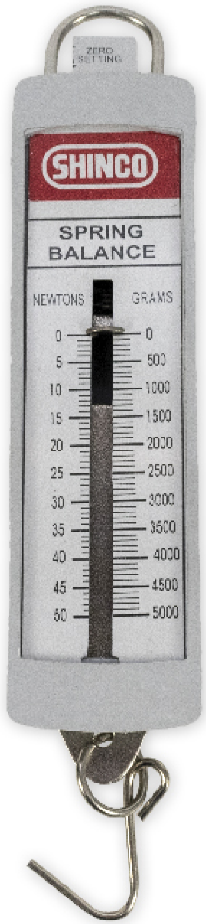
Should we need a steeper incline, we can always move that material more towards the middle.

Some of the tools we will be using:

A protractor:




A spring scale:




The box of coins that we could be sliding down our ramp (*Just for reference, we could end up using other items instead):


A long wooden board that could be used for our incline surface, with possible consideration for other materials as the “ramp” to slide objects on:

**Results / data and analysis -**

1 kilogram = 2.20 pounds

## Wood Block:

Mass of wood block:

0.2 Ibs = 0.2Ibs * $\frac{1kg}{2.20\ Ibs}$ = 0.09kg

Time to slide:

| Trial #: | Time: |
|---|---|
| 1 | 1.98s |
| 2 | 2.07s |
| 3 | 1.97s |
| 4 | 2.09s |
| 5 | 2.05s |

Average time: $\frac{1.98s + 2.07s + 1.97s + 2.09s + 2.05s}{5}$ = 2.03s

Acceleration, which can be determined by rearranging the distance formula we were given:

$d = \frac{1}{2}at^2$ => $a = \frac{2d}{t^2}$

a = $\frac{2(1m)}{(2.03s)^2}$ = 0.49m/s^2

Angle to keep block in equilibrium: 19 degrees

Coefficient of Static Friction:

$\mu_s = tan(\Theta)$

$\mu_s = tan(19^\circ)$ = 0.344

Uncertainty of Coefficient of Static Friction:

$\delta\theta = \frac{\pi}{180} radians$

$\delta\mu_s = (\frac{1}{cos(\theta)})^2 \delta\theta$

$\delta\mu_s = (\frac{1}{cos(19^\circ)})^2 \frac{\pi}{180}$ = 0.02

Work (With regards to force of static friction):

Work = $f_s * Distance$

$f_{s,max} = \mu_s n$ , where n = mass * gravity

$f_{s,max} = \mu_s mgd$

Work = $\mu_s * mass * gravity * distance$
Work = $0.34 * 0.09kg * 9.8m/s^2 * 0m = 0\ Joules$

Angle needed to get block to slide: 20 degrees
Coefficient of Kinetic Friction:
$$\mu_k = tan(\Theta) - \frac{a}{gcos(\theta)}$$
$$\mu_k = tan(20^\circ) - \frac{0.49m/s^2}{9.8m/s^2 cos(20^\circ)} = 0.31$$

Uncertainty of Coefficient of Kinetic Friction:
$$\delta\theta = \frac{\pi}{180} radians$$
$$\delta\mu_k = (sec^2\theta + \frac{atan(\theta)}{gcos(\theta)})\delta\theta$$
$$\delta\mu_k = (sec^2(20^\circ) + \frac{0.49m/s^2 * tan(20^\circ)}{9.8m/s^2 * cos(20^\circ)})\frac{\pi}{180} = 0.02$$

Work (With regards to force of kinetic friction):
Work = $f_k * Distance$
$f_k = \mu_k n$, where n = mass * gravity
$f_k = \mu_k mgd$
Work = $\mu_k * mass * gravity * distance$
Work = $0.31 * 0.09kg * 9.8m/s^2 * 1m = 0.27\ Joules$

## Coin Box:

Mass of coin box:
5.16 Ibs = 5.6 Ibs * $\frac{1kg}{2.20\ Ibs}$ = 2.55kg

Time to slide:

| Trial #: | Time: |
|---|---|
| 1 | 2.93s |
| 2 | 3.15s |
| 3 | 2.97s |
| 4 | 2.95s |
| 5 | 2.82s |

Average time: $\frac{2.93s + 3.15s + 2.97s + 2.95s + 2.82s}{5}$ = 2.96s

Acceleration, which can be determined by rearranging the distance formula we were given:

$d = \frac{1}{2}at^2$ => $a = \frac{2d}{t^2}$

a = $\frac{2(1m)}{(2.96s)^2}$ = 0.23m/s^2

Angle to keep block in equilibrium: 15 degrees
Coefficient of Static Friction:

$\mu_s = tan(\Theta)$

$\mu_s = tan(15^{\circ})$ = 0.27

Uncertainty of Coefficient of Static Friction:

$\delta\theta = \frac{\pi}{180} radians$

$\delta\mu_s = (\frac{1}{cos(\theta)})^2 \delta\theta$

$\delta\mu_s = (\frac{1}{cos(15^{\circ})})^2 \frac{\pi}{180}$ = 0.02

Work (With regards to force of static friction):

Work = $f_s * Distance$

$f_{s,max} = \mu_s n$, where n = mass * gravity

$f_{s,max} = \mu_s mgd$

Work = $\mu_s * mass * gravity * distance$

Work = $0.27 * 2.55kg * 9.8m/s^2 * 0m = 0\ Joules$

Angle needed to get block to slide: 16 degrees
Coefficient of Kinetic Friction:

$\mu_k = tan(\Theta) - \frac{a}{gcos(\theta)}$

$\mu_k = tan(16^{\circ}) - \frac{0.23m/s^2}{9.8m/s^2 cos(16^{\circ})}$ = 0.26

Uncertainty of Coefficient of Kinetic Friction:

$\delta\theta = \frac{\pi}{180} radians$

$\delta\mu_k = (sec^2\theta + \frac{atan(\theta)}{gcos(\theta)})\delta\theta$

$\delta\mu_k = (sec^2(16^{\circ}) + \frac{0.23m/s^2 * tan(16^{\circ})}{9.8m/s^2 * cos(16^{\circ})})\frac{\pi}{180}$ = 0.02

Work (With regards to force of kinetic friction):

Work = $f_k * Distance$

$f_k = \mu_k n$, where n = mass * gravity

$f_k = \mu_k mgd$

Work = $\mu_k * mass * gravity * distance$

Work = $0.26 * 2.55kg * 9.8m/s^2 * 1m = 6.50\ Joules$

**Brick:**

Mass of brick:
2.50 Ibs = 2.50 Ibs * $\frac{1kg}{2.20\ Ibs}$ = 1.14kg

Time to slide:

| Trial #: | Time: |
|---|---|
| 1 | 1.51s |
| 2 | 1.49s |
| 3 | 1.56s |
| 4 | 1.43s |
| 5 | 1.61s |

Average time: $\frac{1.51s + 1.49s + 1.56s + 1.43s + 1.61s}{5}$ = 1.52s

Acceleration, which can be determined by rearranging the distance formula we were given:
$d = \frac{1}{2}at^2$ => $a = \frac{2d}{t^2}$
a = $\frac{2(1m)}{(1.52s)^2}$ = 0.87m/s^2

Angle to keep brick in equilibrium: 28 degrees
Coefficient of Static Friction:
$\mu_s = tan(\Theta)$
$\mu_s = tan(28^\circ)$ = 0.53

Uncertainty of Coefficient of Static Friction:
$\delta\theta = \frac{\pi}{180} radians$
$\delta\mu_s = (\frac{1}{cos(\theta)})^2 \delta\theta$
$\delta\mu_s = (\frac{1}{cos(28^\circ)})^2 \frac{\pi}{180}$ = 0.02

Work (With regards to force of static friction):
Work = $f_s * Distance$
$f_{s,max} = \mu_s n$, where n = mass * gravity
$f_{s,max} = \mu_s mgd$
Work = $\mu_s * mass * gravity * distance$
Work = $0.53 * 1.14kg * 9.8m/s^2 * 0m = 0\ Joules$

Angle needed to get brick to slide: 29 degrees
Coefficient of Kinetic Friction:

$$\mu_k = tan(\Theta) - \frac{a}{g cos(\theta)}$$

$$\mu_k = tan(29^\circ) - \frac{0.87 m/s^2}{9.8 m/s^2 cos(29^\circ)}$$ = 0.45

Uncertainty of Coefficient of Kinetic Friction:

$$\delta\theta \;=\; \frac{\pi}{180} radians$$

$$\delta\mu_k = (sec^2\theta + \frac{a tan(\theta)}{g cos(\theta)})\delta\theta$$

$$\delta\mu_k = (sec^2(29^\circ) + \frac{0.87 m/s^2 * tan(29^\circ)}{9.8 m/s^2 * cos(29^\circ)})\frac{\pi}{180}$$ = 0.02

Work (With regards to force of kinetic friction):

Work = $f_k * Distance$

$f_k = \mu_k n$ , where n = mass * gravity

$f_k = \mu_k mgd$

Work = $\mu_k\ * mass\ * gravity * distance$

Work = $0.45\ * 1.14kg\ *\ 9.8m/s^2 * 1m\ = 5.03\ Joules$

**Error analysis -**

Wood on Wood

$$\% \text{ error} = \frac{|\text{approx} - \text{exact}|}{\text{exact}} \times 100$$

$$= \left|\frac{0.31 - 0.20}{20}\right| \times 100$$

% error = 0.55%

Felt on Wood

$$\% \text{ error} = \frac{|\text{approx} - \text{exact}|}{\text{exact}} \times 100$$

$$= \frac{|0.45 - 0.45|}{0.45} \times 100$$

% error = 0%

*Coincidentally enough, our result for the coefficient of friction of a brick on wood happened to be exact. This was not something we anticipated.

*Also for our box of coins, there were no sources that could tell us what the coefficient of kinetic friction between cardboard and wood is. This may have been a tremendous oversight on our part. As such, we could not determine what our percentage of error was for this part as there was nothing to compare it to.

Some errors we have experienced with regard to this experiment are:
**Incomplete definition (systematic):** Our wooden board that we used as the incline did not exactly have the same texture all over it. Some parts of the board were rougher than others and we noticed while placing our objects on it.
**Failure to account for a factor (systematic):** In our case, we failed to consider whether or not the materials we used could be compared against accurate sources or failed to consider that no one would have thought of measuring the coefficient of kinetic friction of a stuffed cardboard box against wood.
I**nstrument resolution (random):** Our data was limited to what our scale could give us. This limitation was most significant on our wood block, which was the lightest object we could use. We didn't have access to a more accurate scale, which may or may not have been significant.
**Physical variations (random):** Obviously, we can't just get the exact time it takes for an object to slide down a ramp in one try. For this, we decided to get multiple trails and could have been more accurate by increasing the number of our trials.

**Conclusion -**

Again, we designed an experiment to determine a coefficient of kinetic friction between a wooden slab and a wooden block (with other objects being included), as well as the work done by friction. We basically used a wooden slab or wooden board as our incline and increased the angle of the incline until our objects started sliding. Apart from the wooden block that we had experimented with, we used a brick and a small cardboard box full of coins. We used measuring tape, stopwatches, a homemade protractor, and a spring scale to help us with this experiment. We used the spring scale to measure the mass of our objects and took multiple stopwatch trials of our objects sliding down the "ramp" to try and get the average time it takes each object to slide down the ramp.

We were able to conclude that the coefficient of kinetic friction had more to do with the roughness of the materials being used than mass. When you look at the mass of our objects (the brick was 1.14 kg, the block was 0.09kg, and the box was 2.55 kg), you will find that the brick has the highest incline angle (29 degrees) needed to disrupt its state of equilibrium, despite being in the middle between the wooden block and the box of coins in terms of mass (the block needed an incline of 20 degrees above the horizontal plane before sliding and the box only needed 16 degrees). Part of the error in our results, like with the wooden block, came from systematic errors, like in our incomplete definition mentioned above.

For our wooden block, we got a 0.55% error which we attribute to the smoothness of the entire wooden board not being consistent. Our coefficient of kinetic friction was 0.31 with the uncertainty of that coefficient being 0.02, when the exact value of the coefficient of kinetic friction was 0.20. We were also able to determine that the work being done during this time was 0.27 Joules. For our coin box, we could not determine a percentage of error for our results as there were no sources to compare our data to. This was a systematic error on our part, mainly failure to account for a factor. We did not consider that no one else would have had the idea to fill a box with coins and slide it down a wooden ramp for a friction experiment. Our coefficient of kinetic friction was 0.27 with the uncertainty of that coefficient being 0.02. We were also able to determine that the work being done during this time for the box was 6.50 Joules. For our brick, we coincidentally got the exact coefficient of friction that other sources had. We did not look at other sources to see what we should get beforehand. We did our experiment before looking at what we should have gotten. Our coefficient of kinetic friction was 0.45 with the uncertainty of that coefficient being 0.02. The exact coefficient of kinetic friction between a brick and wood was 0.45 according to the sources we found. We were also able to determine that the work being done during this time for the brick was 5.03 Joules. This basically sums up our conclusion.

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