Comparison Between the Order of Coefficients of Rolling and Sliding Friction

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Abstract

Friction force stops or decreases the kinetic energy of a sliding object. However, in rolling objects, for example a wheel, friction force is the source of the translational motion. In this extended essay the order in magnitudes of the coefficients for sliding objects has been compared with the order in magnitudes of the coefficients of rolling objects. In other words do the materials with greater coefficient of sliding friction have a greater coefficient of rolling friction? In our daily life, we use rubber tires for our vehicles. However we may found a material that will be more efficient and safe in driving.

In the experimental stage, a toy car is used and its wheels covered with different materials (rubber, sandpaper, aluminum, wood, leather). Toy car is released from an incline plane which is made of wood. In order to acquire accurate results, variables have been made constant. For each type of wheel, same brand of surface material is used. In each trial toy car is released from five different starting points which are on incline plane. Data obtained from the experiment is used for calculations for the coefficient of rolling friction between wood and material.

The coefficient of rolling friction is calculated for each material with data obtained from the experiment. The results were precise and may contain some minor random errors. Calculated coefficients of rolling friction and the coefficient of sliding friction have been compared. This comparison showed that the order of magnitude between coefficient of friction for sliding objects and coefficient of friction for rolling objects are different. The ordering made between maximum values of literature values for sliding friction coefficients and average experimental values for rolling friction coefficient.

This extended essay contaıns full details on the calculations, conclusion and evaluation of the experiment.

(296 words)

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Introduction

Friction and loss of energy is an escalating issue in our lives. Energy means money and human life turns around earning money. Remarkably in many fields of work is about circulation and transformation of energy. On this spot, energy loss according to friction and efficiency is the subject where many scientist study and try to develop. For a vehicle, energy usage is a vital issue because energy sources that are consumed from them are not renewable and will be expired soon. Since this argument of efficiency of energy used is the most financially invested problem.

Many companies working and developing for reducing energy loss. In transportation sector; transmission of energy from engine to wheels without any loss of energy is not possible. Although the energy loss is not only occur in transmission but also in wheels when they turn the friction between tires and road. This friction correspondingly energy loss is needed to turn energy into movement because friction is the source of translational movement. The wheel is slightly flattened and deformed when it is in contact with surface because of its weight. Since the change in the material, the pattern and the deformation changes and coefficient of rolling friction is effected from these changes.

In this extended essay, the main aim is to compare the order of the coefficients of rolling friction and coefficients of sliding friction in magnitude. Order of the coefficients of rolling friction will be different with the order of coefficients of sliding friction. For translational movement, friction resists the movement. However, if there was no friction, objects cannot roll on a surface. In other words, friction is the source of rolling movement. So that the orders of coefficient for sliding and rolling friction will be thought to be different from each other. In order to calculate the difference, Newton’s laws and work, energy principle is used for the derivation of a new relation in order to calculate the coefficient of rolling friction.

Background Information

The frictional forces acting between surfaces at rest with respect to each other are called forces of static friction. The maximum force of static friction will be the same as the smallest force necessary to start motion. Once motion is started, the frictional forces acting between the surfaces usually decrease so that a smaller force is necessary to maintain uniform motion. Forces acting between surfaces in relative motion are called forces of kinetic friction or sliding friction.

The ratio of the magnitude of the force of sliding friction to magnitude this normal force is called the coefficient of sliding friction. If Fs represented the magnitude of the force of sliding friction. Then;

$$F_s = \mu_s . N$$

Where μ_s is the coefficient of sliding friction.

The actual (microscopic) area of contact is proportional to the normal force, because the contact points deform plastically under the great stresses at develop at these points. The frictional force that opposes one body rolling over another is much less than that for a sliding motion. And this is the advantage of the wheel over the sledge. In rolling, the microscopic contact welds are “peeled” apart rather than “sheared” apart as in sliding friction. This will reduce the frictional force by a large factor.[1]

Derivation of the Relation

Toy car is released from A point and stopped at the end of the B length.

$$F_1 = \mu . N = \mu . mg . cos\theta \ (Friction\ force\ on\ incline\ plane)$$

$$F_2 = \mu . N = \mu . mg (Friction\ force\ on\ horizontal\ plane)$$

Formula is used for sliding friction. However it is used for rolling friction also.

Figure 1: Shows the mechanism of the experiment.

$$W_1 = F_1 . A = \ \mu . mg . cosQ . A \ (work\ done\ by\ friction\ on\ the\ inclined\ plane)$$

$$W_2 = F_2 . B = \ \mu . mg . B \ (work\ done\ by\ friction\ on\ the\ horizontal\ plane)$$

$$PE_{total\ initial} = W_1 + W_2 (total\ energy\ is\ converted\ to\ heat\ by\ work\ done\ by\ friction\ force)$$

$$mg . A . sinQ = \mu . mg . cosQ . A + \ \mu . mg . B$$

$$A . sinQ = \mu . (cosQ . A + B)$$

$$sinQ = \mu . (cosQ + {}^{B}/_{A})$$

$$\mu = \frac{sinQ}{(cosQ + {}^{B}/_{A})}$$

Where;

- F: friction force acting on toy car,
- μ: coefficient of rolling friction,
- N: normal force acting on the toy car,
- A: length of incline plane where toy car is released,
- B: length of flat plane where toy car went until it stops,
- m: mass of the toy car,
- g: gravitational acceleration,
- W: work done by the friction,
- PE: gravitational potential energy

The variation in results will be caused by the difference in B/A values because the sinus and cosine values of the mechanism are constant in all trials.

	Literature Values of Sliding Friction Coefficient
wood vs. leather	0.3-0.4 [2]
wood vs. wood	0.25-0.5 [2]
wood vs. aluminium	0.2-0.6 [2]
wood vs. sandpaper	0.2 - 0.4 [3]
wood vs. plastic	0.70-0.75 [4]

Table 1: Shows the literature data of sliding friction coefficients between the surface and materials used which will be used for the comparison. Literature data are given by intervals because there are too many kinds of materials. So that the comparison will be made by the maximum values of the intervals.

The Order of the Coefficients of Sliding Friction in Magnitude

The Decreasing Order of the Coefficients of Sliding Friction in Magnitude				
1. Place	2. Place	3. Place	4. Place	5. Place
Wood vs. Plastic	Wood vs. Aluminium	Wood vs. Wood	Wood vs. Leather	Wood vs. Sandpaper

Table2: Shows the order of the coefficients of sliding friction in magnitude.

Setting the Experiment Mechanism

During the setup of the experiment, I started with choosing an appropriate surface for sliding. I intended to use wood because it keeps the shape without bending down so I avoid adding unwanted acceleration due to the surface structure. However, forming the incline plane was hard because the angle between the incline plane and ground should be optimized. At first, I tried to make the incline plane's angle with a great grade. However when I raised the beginning of the path, it went down with its weight's acceleration. So I need to decrease the grade of angle in order to create an appropriate mechanism. I didn't want to make the angle so small, because it would make the investigation and result of the experiment harder to observe. The transition place where incline plane and horizontal plane converge, should be flattened to prevent energy loss and to keep the car in its path.

After I chose my surface, I tried to create my own toy car however it didn't go in a linear path. In addition, it was harder to find different wheels, so I find a three wheeled toy car in my school which will be suitable for my experiment.

Figure 2: Shows the toy car that is used in the experimental stage.

When the mechanism setup finished, I measured the incline plane's height *(16.2±0.1cm)*, hypotenuse *(212.2±0.1cm)*. Lengths of which experiment trials will take place is marked by strips *(212.2±0.1cm, 143.2±0.1cm, 111.1±0.1cm, 77.5±0.1cm, 42.4±0.1cm)*.

Figure 3: The mechanism of the experiment is shown in the photo. The toy car's releasing strips can be seen and the meter, which recordings made with, is located from the beginning of the strip.

The first trial was made with rubber wheel from *212.2±0.1cm* in order to check the mechanism. The trial required longer path than I already setup so I added one more wood surface. The second trial was successful and the experiment is started.

Procedure

- Initially, the wheel was made of rubber and the toy car is released 10 times from the different hypotenuse lengths (A) of *212.2±0.1cm, 143.2±0.1cm, 111.1±0.1cm, 77.5±0.1cm, 42.4±0.1cm* and the total distance taken by the car is recorded.

Figure 4: When car stops, the metal stick is located in order to make the recording easier and the result of the releasing is recorded from the data appeared from the meter.

- Secondly, wheels of toy car are covered with sandpaper and 10 trials of total distance is obtained for each hypotenuse lengths (A) of *212.2±0.1cm, 143.2±0.1cm, 111.1±0.1cm, 77.5±0.1cm, 42.4±0.1cm* and data is recorded. The sandpapers are uncovered from the wheels.

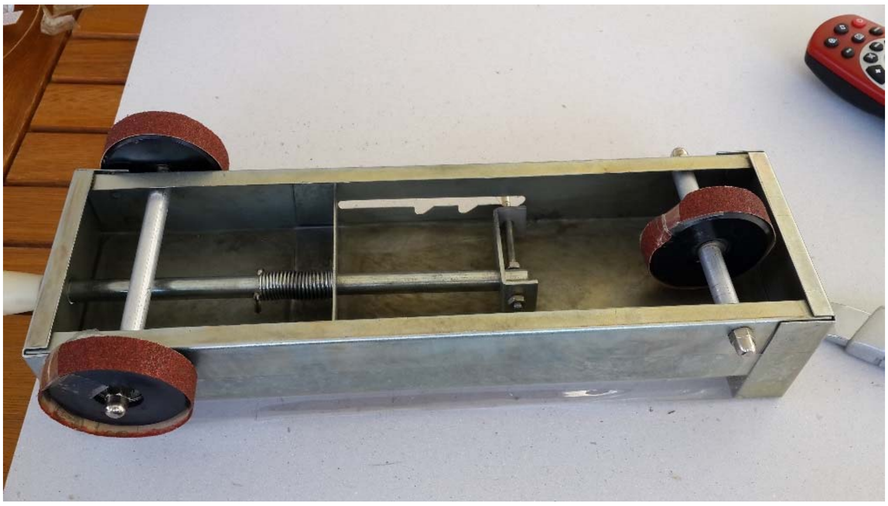


Figure 5: Shows the wheels that are covered with sandpaper.

- Thirdly, wheels are covered with aluminium and 10 trials of total distance is obtained for each hypotenuse lengths (A) of *212.2±0.1cm, 143.2±0.1cm, 111.1±0.1cm, 77.5±0.1cm, 42.4±0.1cm* and data is recorded. The aluminum is uncovered from the wheels and data is recorded.

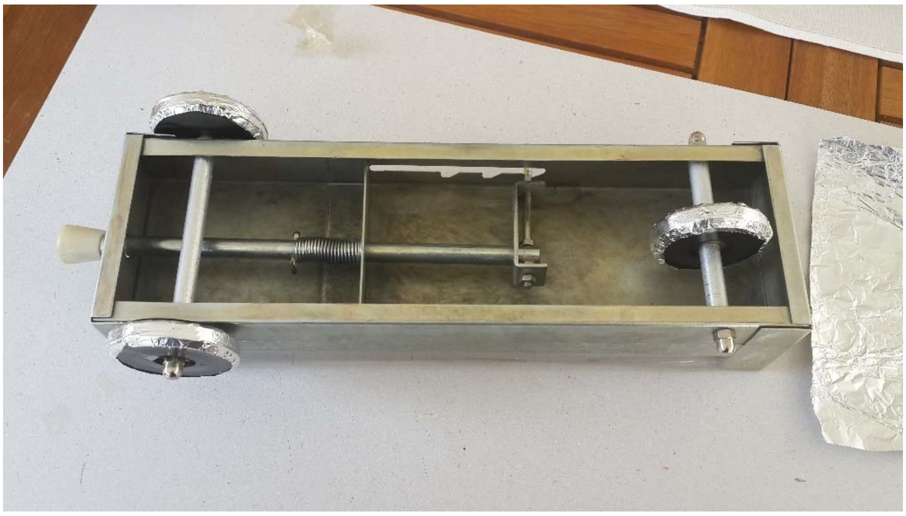


Figure 6: Shows the wheels that are covered with aluminium.

- Fourthly, wheels of toy car are covered with wood and 10 trials of total distance is obtained for each hypotenuse lengths (A) of *212.2±0.1cm, 143.2±0.1cm, 111.1±0.1cm, 77.5±0.1cm, 42.4±0.1cm* and data is recorded. The wood are uncovered from the wheels and data is recorded.

Figure 7: Shows the wheels that are covered with wood.

- Finally, wheels of toy car are covered with leather and 10 trials of total distance is obtained for each hypotenuse lengths (A) of *212.2±0.1cm, 143.2±0.1cm, 111.1±0.1cm, 77.5±0.1cm, 42.4±0.1cm* and data is recorded. The leather is uncovered from the wheels and data is recorded.

Figure 8: Shows the wheels that are covered with leather.

Control Variables

Since this extended essay is about the nature of physics where every force has an antagonistic force against itself. I needed to work careful to prevent mistakes. In the experimental stage the main problem was to regulate control variables which will affect the result of the experiment. In order to reduce the random errors, the number of trials are increased and due to this situation preciseness is increased.

1. Surface Area of the Wheels:

   The area of intersection is the most important thing in this extended essay because the intersection area of wheel with surface affects the friction area so the friction loss will not be produced from only one variable and the result of the experiment is affected from this situation. I choose to cover the rubber wheel in order not to change the intersection area.

2. Gravitational Acceleration and Weight:

   The friction force is produced from the normal force, weight, so it is important to regulate the weight while covering the wheels of toy car because it directly affects the weight of the toy car so the normal force acting on the toy car. The experiment had occurred where the gravitational acceleration is 9,806 m.s^{-2} in Ankara. Increase in the weight directly increases the effect of rolling friction so that energy loss occurs.

3. Same Surface and Path

   All of the trials are made on the same surface in order to prevent different results and systematic errors. In this experiment, the path and surface is one of the most important factors that affects the result of the experiment. Because the friction force is dependent to surface and if the surface is effected the results would be misleading.

4. Same Sine and Cosine Values of Mechanism

   In the derived relation of coefficient of rolling friction, there are sinus and cosine values of the mechanism and a variation in their values would affect all of the results of trials so that the sinus and cosine values are made constant in all trials.

Data Processing

Raw Data Tables

Rubber

	Hypotenuse Lengths (Distance A)				
	212.2 (±0.1 cm)	143.2 (±0.1 cm)	111.1 (±0.1 cm)	77.4 (±0.1 cm)	42.4 (±0.1 cm)
1st Trial	570.7	463.8	314.8	233.8	188.5
2nd Trial	585.6	465.1	320.2	251.8	199.2
3rd Trial	508.4	468.2	318.1	260.6	189.3
4th Trial	571.9	467.4	315.9	258.2	189.8
5th Trial	512.8	464.7	322.6	260.9	182.9
6th Trial	556.6	467.3	322.9	249.4	178.5
7th Trial	569.4	467.5	323.1	266.7	175.1
8th Trial	600.8	470.9	342.1	246.1	176.2
9th Trial	485.3	457.8	312.1	251.8	186.3
10th Trial	591.2	466.7	317.4	255.4	182.6

Table3: Total distance values (A+B) taken by the toy car, with rubber wheels, until it stops, for each values of hypotenuse lengths (A).

Figure 9: Shows where are A and B places in the mechanism of the experiment so that the comprehensibility of the Table X increase.

Figure 10: Shows the mechanism of the experiment.

Sandpaper

	Hypotenuse Lengths				
	212.2 (±0.1 cm)	143.2 (±0.1 cm)	111.1 (±0.1 cm)	77.4 (±0.1 cm)	42.4 (±0.1 cm)
1st Trial	420.0	543.4	400.6	262.2	181.4
2nd Trial	420.8	544.7	347.5	227.7	182.1
3rd Trial	424.1	505.7	415.7	228.7	140.7
4th Trial	417.5	479.1	414.4	237.1	144.4
5th Trial	426.1	460.8	413.8	208.5	147.9
6th Trial	439.9	462.9	408.9	259.6	153.1
7th Trial	422.2	498.9	409.1	248.8	155.2
8th Trial	425.3	484.3	419.1	246.3	155.5
9th Trial	423.6	464.1	348.2	264.7	130.1
10th Trial	442.3	474.4	394.7	265.6	129.4

Table 4: Total distance values (A+B) taken by the toy car, with sandpaper wheels, until it stops, for each values of hypotenuse lengths (A).

Aluminium

	Hypotenuse Lengths				
	212.2 (±0.1 cm)	143.2 (±0.1 cm)	111.1 (±0.1 cm)	77.4 (±0.1 cm)	42.4 (±0.1 cm)
1st Trial	572.9	335.9	266.6	195.3	124.3
2nd Trial	597.3	336.7	269.3	193.2	119.4
3rd Trial	615.3	326.8	264.8	208.3	133.1
4th Trial	586.4	348.2	261.1	193.4	130.4
5th Trial	597.7	347.7	272.9	196.3	128.7
6th Trial	603.0	350.3	267.1	196.1	129.3
7th Trial	581.4	339.9	271.1	194.6	131.1
8th Trial	547.2	349.4	266.9	194.8	129.9
9th Trial	624.1	338.8	273.2	198.1	132.8
10th Trial	604.1	335.4	282.8	203.1	131.4

Table 5: Total distance values (A+B) taken by the toy car, with aluminium wheels, until it stops, for each values of hypotenuse lengths (A).

Wood

	Hypotenuse Lengths				
	212.2 (±0.1 cm)	143.2 (±0.1 cm)	111.1 (±0.1 cm)	77.4 (±0.1 cm)	42.4 (±0.1 cm)
1st Trial	510,3	348,4	232,2	171,7	125,2
2nd Trial	493,5	351,3	216,1	180,8	127,2
3rd Trial	509,2	347,9	212,3	184,3	120,1
4th Trial	526,1	343,7	226,1	174,9	122,7
5th Trial	525,1	355,1	223,4	178,9	120,3
6th Trial	509,0	337,8	225,9	171,4	128,4
7th Trial	441,7	341,1	224,3	174,1	122,7
8th Trial	511,7	320,4	222,6	170,5	125,2
9th Trial	512,0	336,1	230,4	185,1	124,4
10th Trial	436,6	328,6	236,5	188,8	124,5

Table 6: Total distance values (A+B) taken by the toy car, with wood wheels, until it stops, for each values of hypotenuse lengths (A).

Leather

	Hypotenuse Lengths				
	212.2 (±0.1 cm)	143.2 (±0.1 cm)	111.1 (±0.1 cm)	77.4 (±0.1 cm)	42.4 (±0.1 cm)
1st Trial	327,1	246,5	309,8	195,1	136,2
2nd Trial	333,8	248,4	291,7	183,8	131,1
3rd Trial	347,3	246,8	306,6	194,2	135,3
4th Trial	265,4	249,3	305,5	191,7	133,6
5th Trial	336,7	258,2	321,2	193,6	138,1
6th Trial	339,8	261,4	310,4	184,6	136,5
7th Trial	340,0	249,9	309,1	194,4	137,1
8th Trial	337,8	258,9	325,8	188,9	134,7
9th Trial	350,9	251,4	305,3	184,5	133,2
10th Trial	341,3	266,6	314,9	185,1	137,4

Table7: Total distance values (A+B) taken by the toy car, with leather wheels, until it stops, for each values of hypotenuse lengths (A).

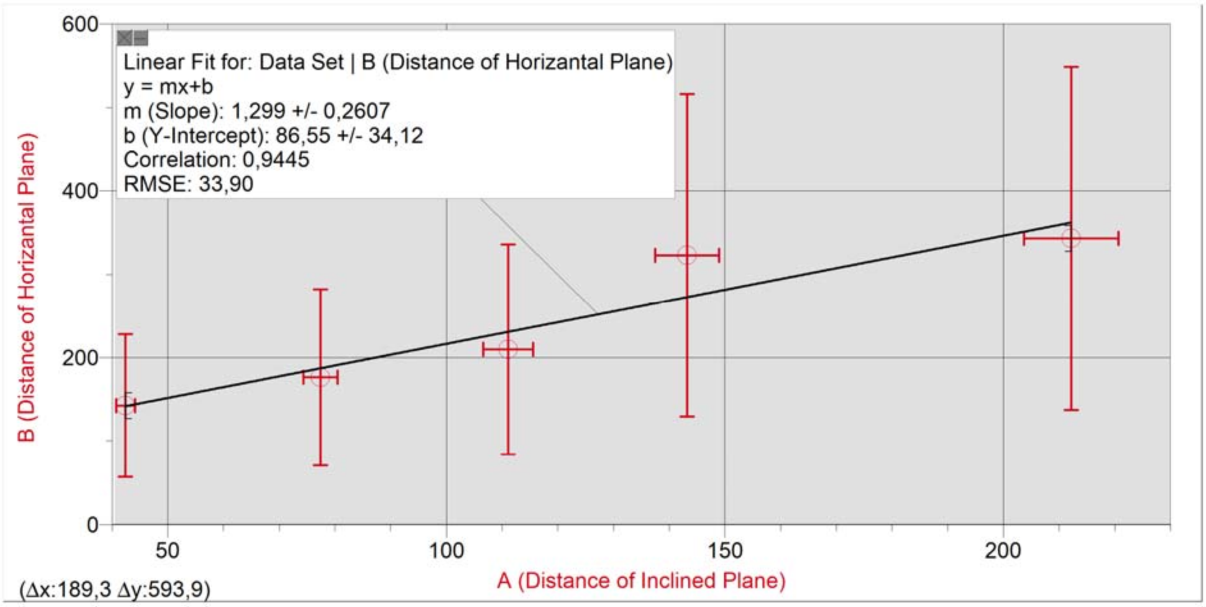
Analysis of the Data

B/A Graphs of the Materials

Before drawing the graphs of the materials, the B values are found by subtracting the A values form the average (A+B) values. When B values are found, their average is calculated and typed to Y-axis with the A values typed to X-axis in order to draw the best line of the graph so that the slopes will be found. These slopes will be used for comparison for coefficient of rolling friction. The greater value of slope of B/A will decrease the magnitude of rolling friction as it is seen in the relation. Because B/A is at the denominator part of the relation and in mathematics if denominator is increased the magnitude of the fraction is decreased.

$$\mu = \frac{sinQ}{(cosQ + {}^{B}/_{A})}$$

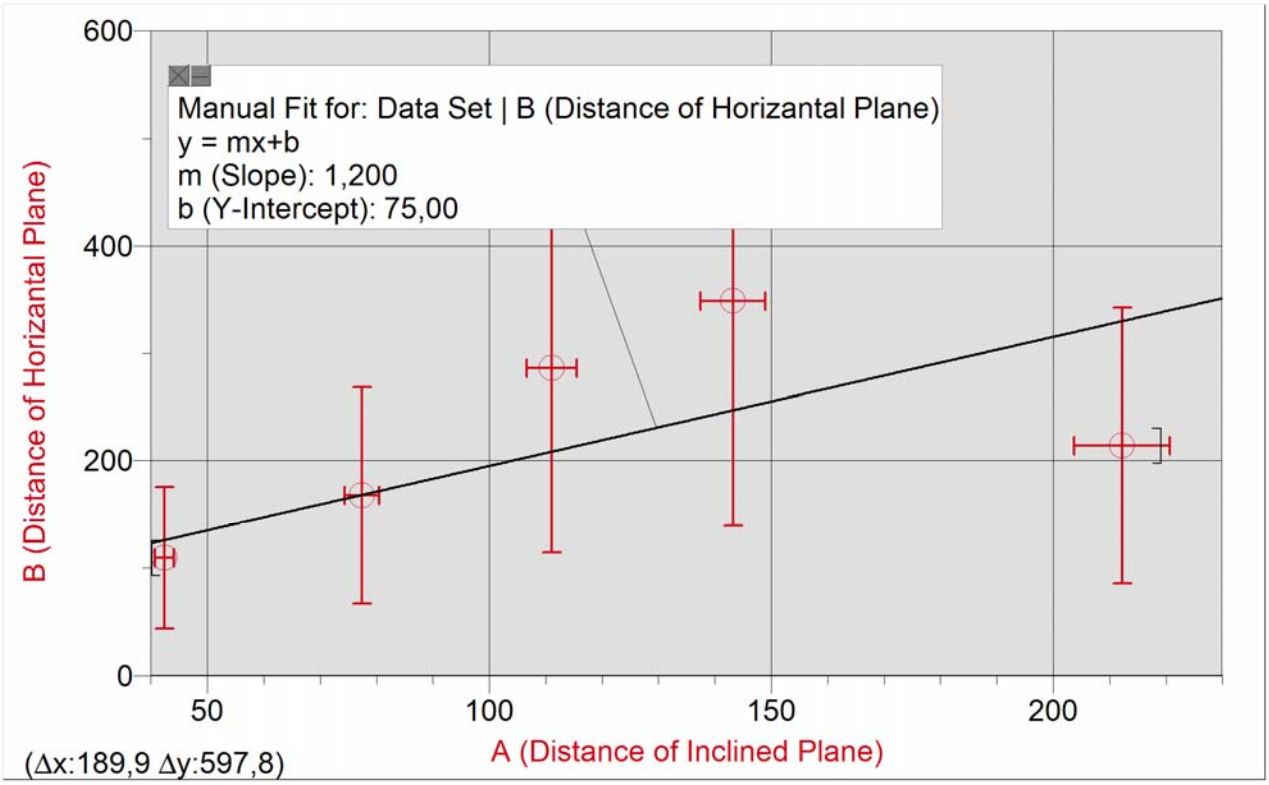
Rubber



Graph 1: Shows graph, for rubber, the average B values versus A values whose gradient changes the coefficient of rolling friction.

$$Slope\ of\ the\ Best\ line = {}^{B}/_{A} = 1{,}29$$

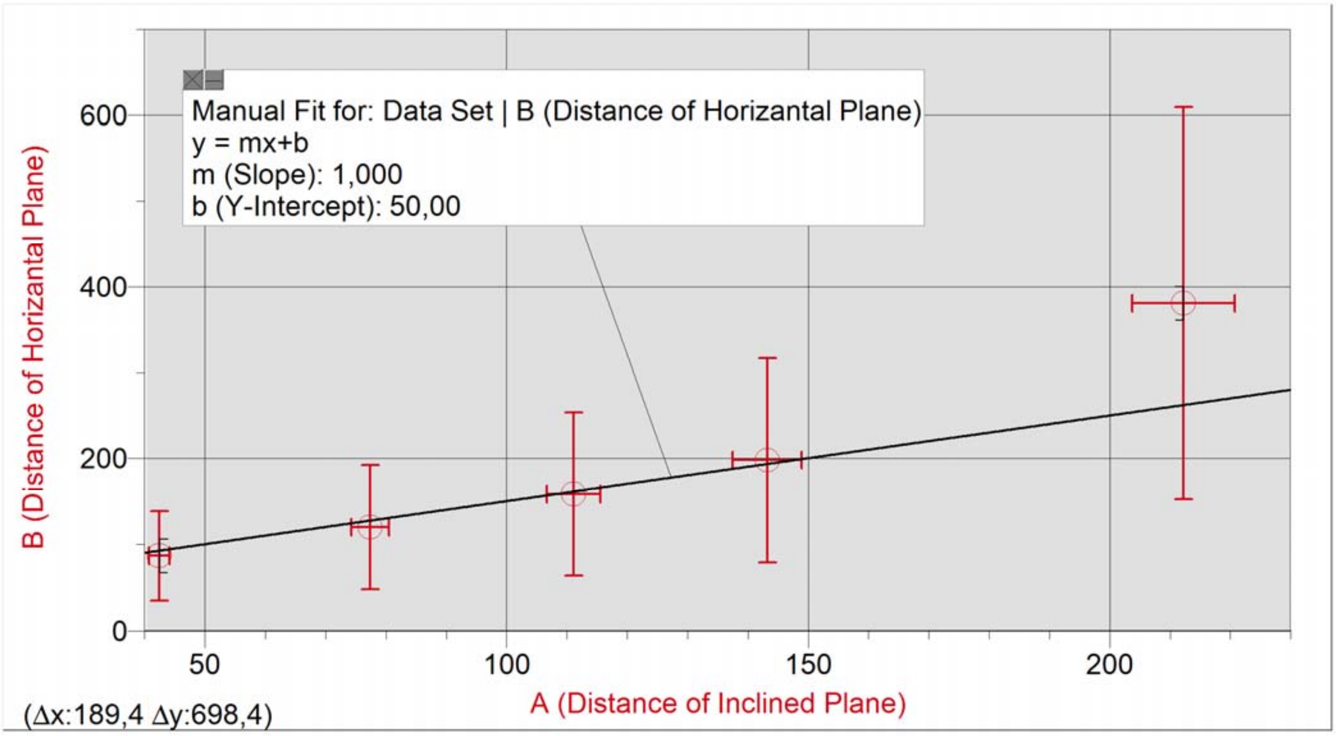
Sandpaper



Graph 2: Shows graph, for sandpaper, the average B values versus A values whose gradient changes the coefficient of rolling friction.

$$Slope\ of\ the\ Best\ line = {}^{B}/_{A} = 1{,}20$$

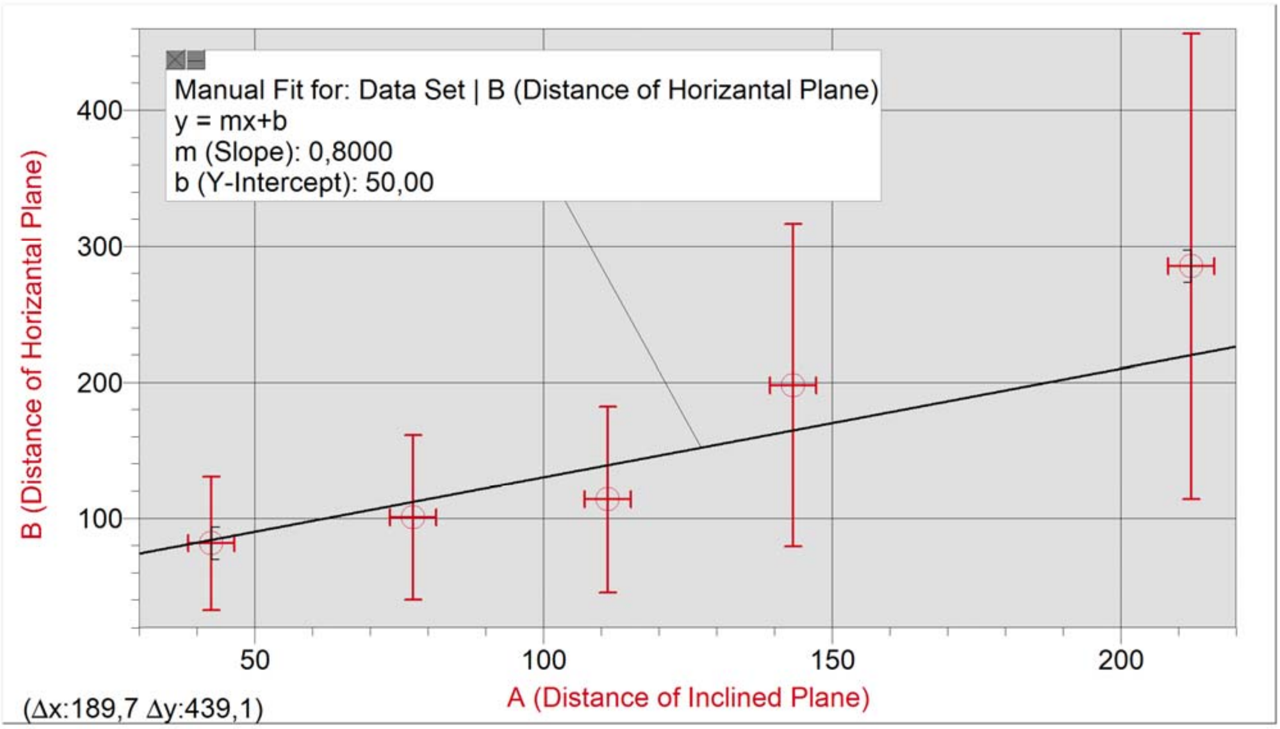
Aluminium



Graph 3: Shows graph, for aluminium, the average B values versus A values whose gradient changes the coefficient of rolling friction.

$$Slope\ of\ the\ Best\ line = {}^{B}/_{A} = 1{,}00$$

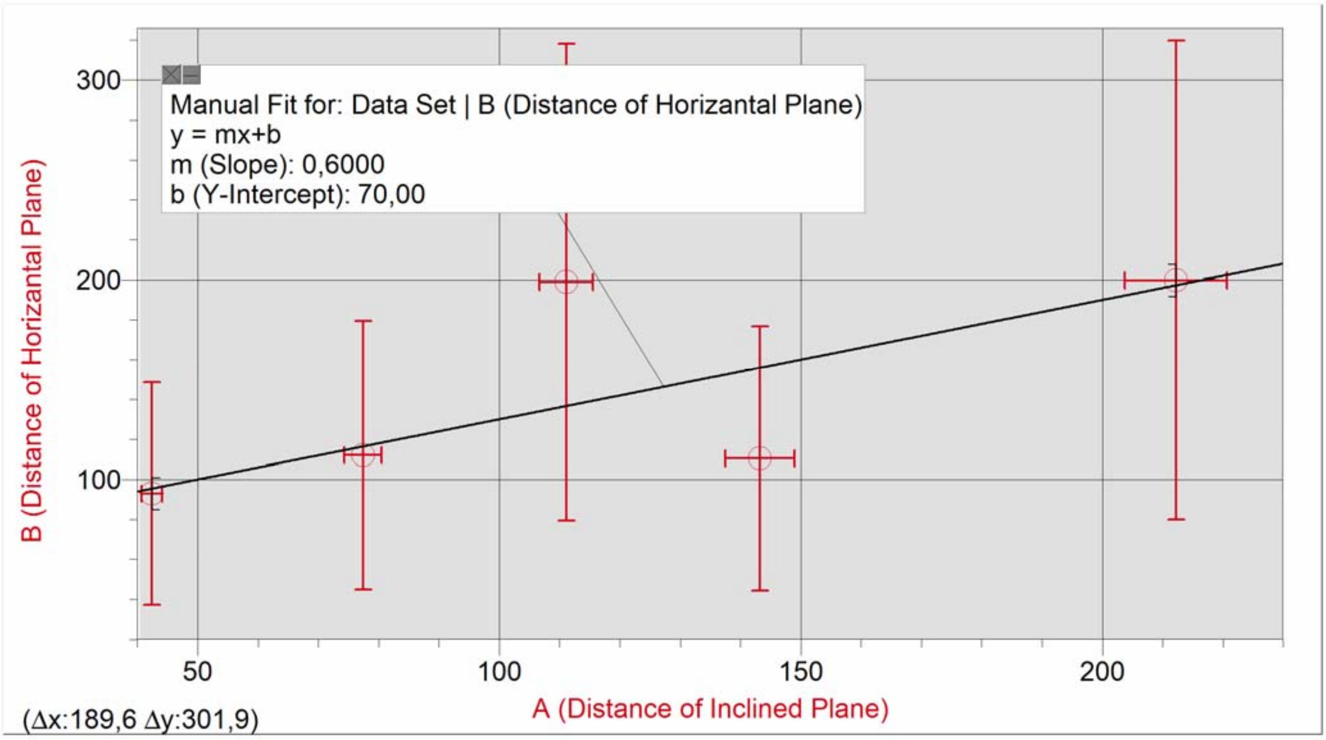
Wood



Graph 4: Shows graph, for wood, the average B values versus A values whose gradient changes the coefficient of rolling friction.

$$Slope\ of\ the\ Best\ line = {}^{B}/_{A} = 0{,}80$$

Leather



Graph 5: Shows graph, for leather, the average B values versus A values whose gradient changes the coefficient of rolling friction.

$$Slope\ of\ the\ Best\ line = {}^{B}/_{A} = 0{,}60$$

Calculation of the Coefficient of Rolling Friction

The derived relation of coefficient of rolling friction is;

$$\mu = \frac{sinQ}{(cosQ + {}^{B}/_{A})}$$

Where;

Figure 11: Shows where the sinQ, cosQ, B and A are in the mechanism of the experiment.

With this relation and previously found B/A values we are able to calculate the coefficient of rolling friction. However in the graphs there is too much uncertainty and the slope can vary too much. However the order of the slopes can be used for comparison. In order to make more precise calculations, the average of all trials for each A value is calculated and used for calculations. Sine and cosine values are nearly equal for each A value however there might have been bending down in the mechanism so that h and A.cosQ values are measured for all A values.

Sample Calculation

- Wood vs. Sandpaper

$$A = 42.4\ cm, \qquad h = 5.1\ cm, \qquad A.cosQ = 41.8cm$$

$$Average\ B\ value = 109.4\ cm$$

$$\mu = \frac{sinQ}{\left(cosQ + {}^{B}/_{A}\right)}$$

$$\mu = \frac{\frac{5.1}{42.4}}{\frac{41.8}{42.4} + \frac{109.4}{42.4}}$$

$$\mu = \frac{5.1}{41.8 + 109.4}$$

$$\mu = 0.033$$

Sample Error Calculation

- Wood vs. Sandpaper

$$\mu = \frac{sinQ}{\left(cosQ + {}^{B}/_{A}\right)}$$

$$\mu_{max} = \frac{\frac{16.2}{212.2}}{\frac{210.4}{212.2} + \frac{213.98}{212.2}}$$

$$\mu_{max} = \frac{16.2}{210.4 + 213.98}$$

$$\mu_{max} = 0.0381$$

$$\mu_{min} = \frac{\frac{9.6}{111.1}}{\frac{110.6}{111.1} + \frac{286.1}{111.1}}$$

$$\mu_{min} = \frac{9.6}{110.6 + 286.1}$$

$$\mu_{min} = 0.0241$$

$$Uncertainty = \frac{\mu_{max} - \mu_{min}}{2}$$

$$\frac{0.0381 - 0.0241}{2} = 0.007 = 7x10^{-3}$$

All these steps are made for each material and each A values. In order to minimize the random error, all of the coefficients of rolling friction, which are calculated by the relation for each A values, averaged and calculated.

	Average Coefficients of Rolling Friction (μ)	Literature Values of Sliding Friction Coefficient
Wood vs. Leather	0.040 ± 9.10^{-3}	0.3-0.4 [2]
Wood vs. Wood	0.038 ± 5.10^{-3}	0.25-0.5 [2]
Wood vs. Aluminium	0.034 ± 6.10^{-3}	0.2-0.6 [2]
Wood vs. Sandpaper	0.029 ± 7.10^{-3}	0.2 - 0.4 [3]
Wood vs. Rubber	0.028 ± 2.10^{-3}	0.70-0.75 [4]

Table 8: Shows the calculated average coefficients of rolling friction and the literature values of sliding friction coefficient. The comparison will be made with these data.

Comparison

The Order of the Coefficients of Sliding Friction in Magnitude				
1. Place	2. Place	3. Place	4. Place	5. Place
Wood vs. Rubber	Wood vs. Aluminium	Wood vs. Wood	Wood vs. Leather	Wood vs. Sandpaper
The Order of the Coefficients of Rolling Friction in Magnitude				
1. Place	2. Place	3. Place	4. Place	5. Place
Wood vs. Leather	Wood vs. Wood	Wood vs. Aluminium	Wood vs. Sandpaper	Wood vs. Rubber

Table 9: Shows the order of coefficients of sliding friction and rolling friction. The comparison can be made with this table.

Conclusion and Evaluation

Conclusion

In this extended essay, the main aim is to compare the order of the coefficients of rolling friction and coefficients of sliding friction in magnitude. The topic was worthy for investigation because when I was surveying my physics book, I came up to a question: “Does a material with high coefficient of sliding friction have a high coefficient of rolling friction?” In translational movement, friction resists the movement of the object. Nonetheless, if there was no friction, objects would not roll on a surface. Especially, friction is the source of rolling movement because if it did not occur, the objects would slide on surfaces.

In order to investigate this circumstance, I have set an inclined plane and take a three wheeled toy car from the school. I found some materials that can be covered to the wheels and I have released the toy car from the inclined plane and observed its movement with different wheels. I have found the literature values of sliding friction coefficient for each material. After the experimental stage, I have derived a relation between the coefficients of rolling friction and the data obtained from the experiment.

$$\mu = \frac{sinQ}{(cosQ + {}^{B}/_{A})}$$

Firstly, I intended to use the B/A graphs and their slopes for the comparison. Because as it is seen in the relation B/A is the changing factor in the relation. The B/A slopes might be a measure of coefficient of rolling friction. However, in the graphs the uncertainty is at a great amount so the slopes can vary too much. So I decided to use the data from the experiment and put the data into the relation to increase precision.

With this relation I have calculated the coefficients of rolling friction for each material that is used for the covering. After the end of the calculations, I have ordered the coefficients of rolling friction in magnitude. When I found all of the results, I have compared if the order of the coefficients of rolling friction is the same with the order of literature values of sliding friction coefficients.

In order to clarify the result, the coefficient of sliding friction of wood vs. plastic is the biggest however in the order of coefficients of rolling friction wood vs. plastic is at last place. In the order of coefficients of sliding friction, the coefficient between wood vs. aluminium was at second place where the coefficient of rolling friction between wood vs. aluminium is at third place. The coefficient of sliding friction between wood vs. wood is at third place at the order where the coefficient of rolling friction between wood vs. wood is at second place at the order. The coefficient of sliding friction of wood vs. leather is at fourth place where it is first place at coefficient of rolling friction. Lastly the coefficient of sliding friction between wood vs. sandpaper is at last place however coefficient of rolling friction is at fourth place. The ordering was different and I can say that materials with high coefficients of sliding friction do not have a high coefficient of rolling friction as it is seen in the Table X.

Evaluation

In this extended essay, the experimental stage is vital because the experimental data is used for calculations. However in the experimental stage if several things was better, the data would be more accurate;

- If the surface of the mechanism was stronger, it would be better because sometimes unwanted accelerations occurred and it affected the result of the experiment.
- If the surface was a single peace it would be better because even I have flattened the converging place of two pieces of surface, sometimes toy cars wheels effected from the transition and go away from the path.

- If the angle of the inclined plane was greater in magnitude the incline plane was sliding to minimize the angle because it could not lift its weight.
- If the wheels were made of the different materials it would be better because the covering composed problems. For example, while covering leather I needed to use glue and glue was so rigid that, it created a height difference in the surface of wheel.
- Experiment is about friction between two surfaces and in experiment I used same toy car and same wheel to be covered so that there might be deformation in the toy car and the result of the experiment be effected from it. So if identical toy cars and identical wheels is used, the result would be more and more consistent.
- The experiment is made in macroscopic scale, however it is known that friction is effected by microscopic surfaces of two materials so that this might have created minor errors.
- The data uptake is made with a meter which is not well at reading of the result so if there was a system which will have a camera and a meter that would give the result of the trials, the random errors caused by the person who does the experiment.

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Bibliography

- [1] Halliday, D., & Resnick, R. (2014).*Principles of physics* (10.th ed.). Hoboken, NJ: Wiley.
- [2] Coefficient of Friction Values for Clean Surfaces. (n.d.). Retrieved February 27, 2015, from http://www.school-for-champions.com/science/friction_coefficient.htm
- [3] Friction and Coefficients of Friction. (n.d.). Retrieved February 27, 2015, from http://www.engineeringtoolbox.com/friction-coefficients-d_778.html
- [4] Nordin, M. (2012). *Fundamentals of biomechanics: Equilibrium, motion, and deformation* (3.rd ed.). New York [u.a.: Springer.
- [5] ASKİ Genel Müdürlüğü - Ankara Su Kanalizasyon İdaresi Genel Müdürlüğü. (n.d.). Retrieved February 27, 2015, from http://www.aski.gov.tr/tr/398-3-grup-83-kalem-pompa-vana-ve-derinkuyu-malzemesi-alimi-ihalesi.html