Forrest Moulin

A MODEL FOR KINETIC FRICTION - PART 1

INTRODUCTORY INSTRUCTIONS

This lab will be partially graded using scientific ability rubrics. To help you know what we expect, the rubrics have been included along with the instructions for each question. If no rubric is indicated, the question is graded on completeness.

Lab goals: In this lab, you will

1) Learn to use the force sensor on the IOLab.
2) Determine different methods to measure kinetic friction.

Observing experiments: Read carefully the accompanying "Observing experiment" file which explains what we expect you to do in observing experiments such as the ones below and what we expect you to write in response to the questions.

Equipment available: **You will need the IOLab with computer/software and a horizontal surface. You may need the "hook" attachment and a small piece of string to pull the IOLab.**

Phenomenon to Observe: When two objects in contact move relative to one another, the atoms at the interface interact electrically to create a force that resists the motion. This force is called kinetic friction and we know that it is always in the direction opposite to motion and parallel to the interface. We would like to investigate different ways to measure and quantify kinetic friction.

Variables:

- Independent variable: mass of the IOLab
- Dependent variable 1: measured kinetic friction
- Dependent variable 2: measured kinetic friction by an alternative method.
- Controlled variables. Surface on which IOLab slide, temperature of the room or surfaces, etc..

Both dependent and independent variables are **quantitative variable** (they could be any numbers).

Primary Guiding Questions to think about:

1. How can we measure kinetic friction (in Newton?)
2. Does kinetic friction remain mostly the same during the sliding phase. Does the friction change between a big/small push or for a continuous pull?
3. What overall properties of the object does kinetic friction depend on? Does it depend on shape, surface area of contact, mass?

Some of these questions can be answered (at least partially) from our analysis in lab 2 "slowing down". The dependence on shape or surface area are hard to do quantitatively with the material we have so we will focus on dependence on mass.

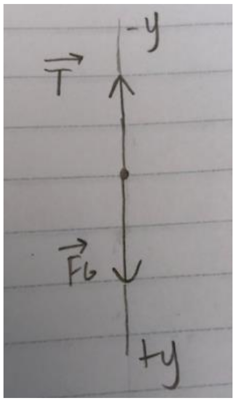
ACTIVITY 1: DISCOVERING THE FORCE SENSOR AND MEASURING THE MASS OF THE IOLAB

Set-up
1. Turn on the IOLab and select the force sensor.
2. Recalibrate the force sensor and the accelerometer to make sure the calibration is up to date.
3. Attach the hook.
4. Hit record and immediately "rezero" the force sensor. You will need to do this frequently.

1. A first thing to do is to check the direction of pull versus push. Push on the hook. Is the force positive or negative? Does pulling give you the opposite? Does this make sense with the coordinate system given on the IOLab?

Pushing on the hook creates a force in the positive y-direction, and pulling on the hook creates a force in the negative y-direction.

2. Now hold the IOLab by the hook, so that it is hanging in the air. Draw (by hand, take a picture or using software) the FBD for this situation, being careful to draw the coordinate system that corresponds to the one used by the IOLab remote. Write Newton's Second Law $\vec{F} = m\vec{a}$ for this situation for the component(s) you think is/are relevant.

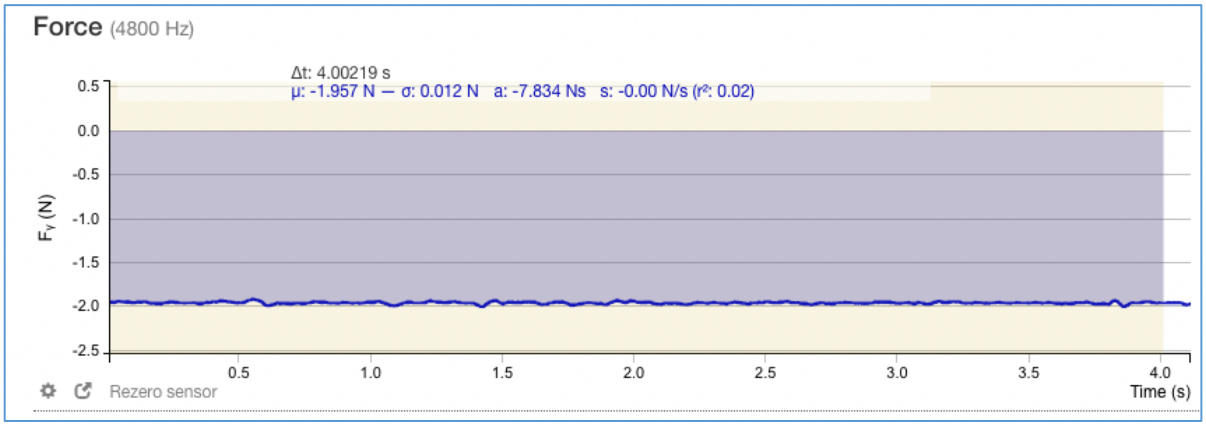


$\overrightarrow{F_G} = mg \qquad \vec{T} = -mg$

3. What is the force of gravity (F_G) on the IOLab? Specify the magnitude and the direction.

$\overrightarrow{F_G} = +mg \approx 2N$ since the IOLab's hook is pointed in the negative y-direction.

4. Take a screenshot of your F(t) graph, highlighting the region used to determine the average force with the statistical tool.



The average force over a period of about 4 s was -1.957 N, designated by the statistical mean μ.

5. Calculate the mass of the IOLab and explain how you can get this from the measurement of the force of gravity.

$F_G = mg$, so $m = \frac{F_G}{g} = \frac{1.957}{9.8} \approx 0.2$ kg.

6. Now move the IOLab up or down at constant velocity. Does the tension change? Write Newton's Second Law when the IOLab moves up or down at constant velocity.

When the IOLab is moved up or down at constant velocity, the tension does not change and there is no acceleration ($\vec{a} = \frac{\overrightarrow{\Delta v}}{\Delta t} = \frac{0}{\Delta t} = 0\ m/s^2$). $\overrightarrow{F_{net}} = m\vec{a} = 0.2(0) = 0\ N$.

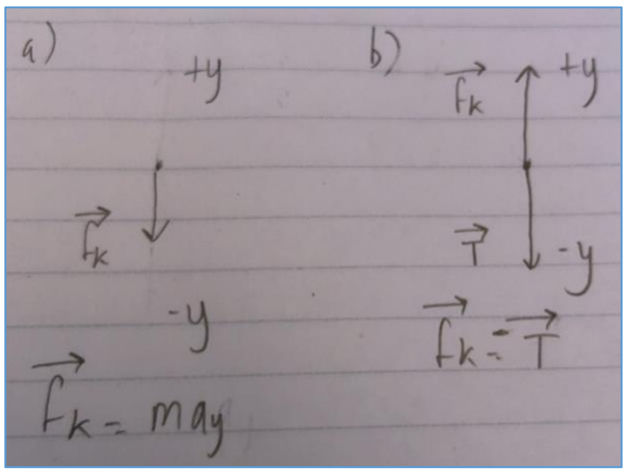
ACTIVITY 2: OBSERVING EXPERIMENT: HOW TO MEASURE KINETIC FRICTION

7. There are two ways to measure the kinetic friction force. **We will always measure the kinetic friction with the wheels up and the IOLab on its felt pads.

   a. **Method A.** First, you can push the IOLab and measure the average acceleration during the slide using the **accelerometer**.
   b. **Method B**. Second, you can pull the IOLab with a string or directly with the hook at nearly constant velocity and use the **force sensor** to measure the tension.

Draw a FBD for each situation and explain with equations how the kinetic friction is determined in each case (determined using the IOLab sensor, so accelerometer or force sensor). Take a picture of your work and include it here.

Graded correctness.



Method A is very similar to the big/small push we did in lab 2 and you should remind yourself your preferred way to measure the average acceleration (from where to where, etc.)

Method B is new so let us go into more details before we actually use it to measure the kinetic friction.

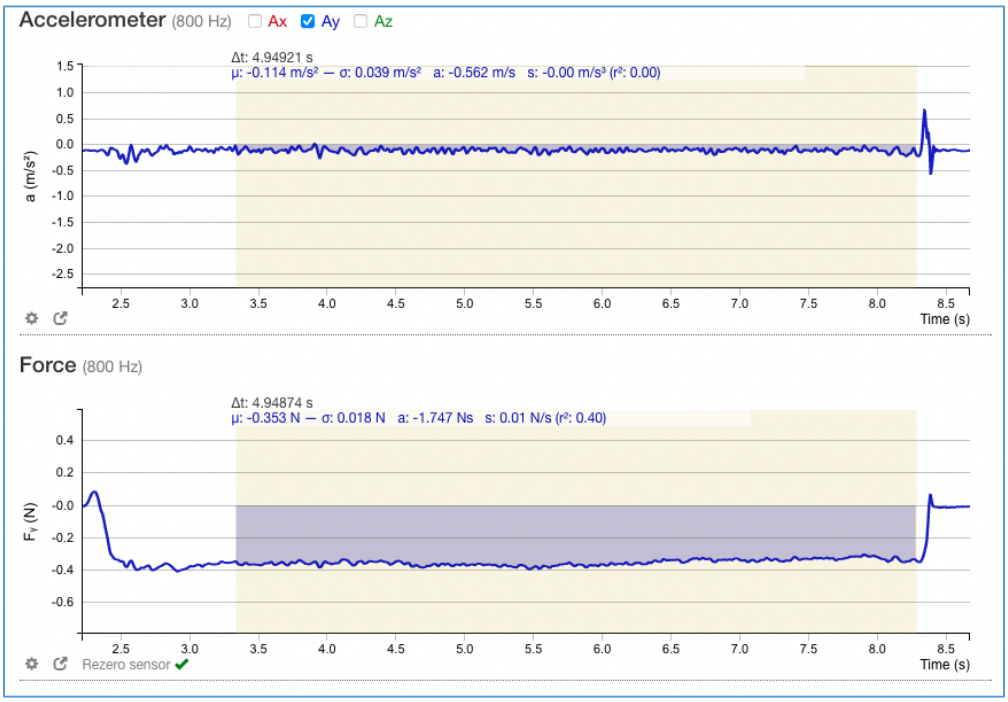
8. Pull your IOLab at constant velocity and record its motion. Describe, <u>**without trying to explain**</u>, what you observe in your data when the IOLab is moving at constant velocity

** In this type of question, you should write everything that could be important for any future investigations, you are making a report on everything you see and notice. Write down even small seemingly unimportant details. Do not seek to explain yet! You may want to look at both the accelerometer and the force sensor.

	Inadequate	Adequate	Good
Is able to describe what is observed without trying to explain.	A description is incomplete. Or, observations are adjusted to fit expectations.	A description is complete but mixed up with explanations or pattern.	Clearly describes what happens in the experiments.

Notes from the first attempt of Method B:

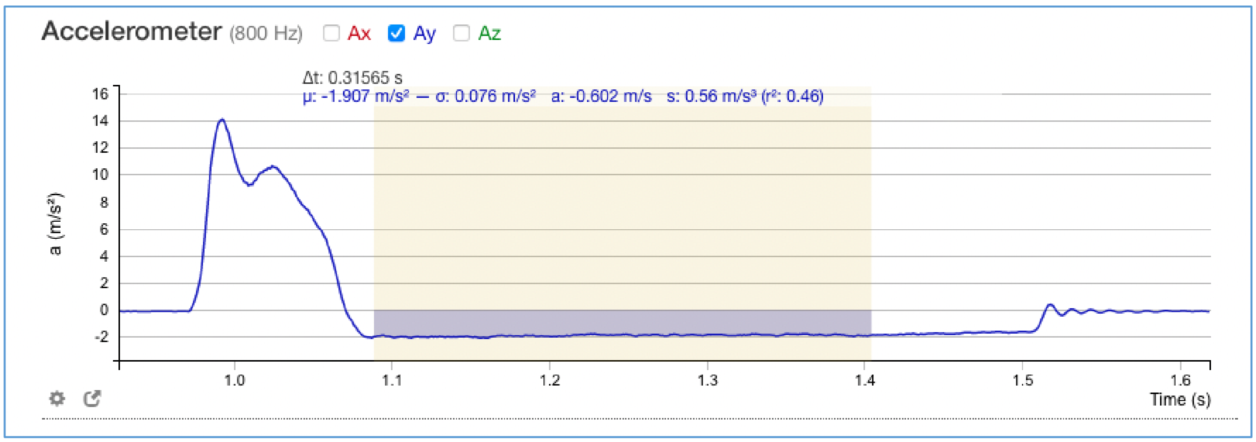
- Initial acceleration a_y with the device at rest was -0.116 m/s^2.
- The acceleration dropped to a minimum value of -0.368 m/s^2 within the first second and then remained at an average value of $-0.114\ m/s^2$ during a Δt of about 4.9 s.
- The average velocity during the Δt of about 4.9 s was approximately -0.562 m/s.
- Initial F_y with the device at rest was 0.003 N after the force sensor was rezeroed.
- The force dropped quickly to a minimum value of -0.409 N within the first second and then remained at an average value of -0.353 N during the same period Δt of about 4.9 s.
- When the device stopped moving the acceleration and force values increased quickly at about t = 8.3 s.



9. Let us summarize. We are interested in measuring the average kinetic friction on the IOLab. Describe precisely how to measure the average kinetic friction using both methods, A and B. Which sensors will you use? What quantities are you measuring? How do you intend to calculate their average values (from where to where)? What computation do you need to do to get the final answer?

	Inadequate	Adequate	Good
Is able to describe how to use available equipment to make measurements	All chosen measurements can be made, but no details are given about how it is done.	All chosen measurements can be made, but the details of how it is done are vague or incomplete.	All chosen measurements can be made and all details of how it is done are clearly provided.

Method A: Use the accelerometer to measure the average acceleration of the sliding phase, which can be measured during the period in which the slope of the acceleration was approximately 0 (constant acceleration). Then, calculate f_k by multiplying the mass times the average acceleration (0.2 kg x -1.907 m/s^2 = -0.381 N).



Method B: Use the accelerometer in combination with the force sensor. Start with the IOLab device at rest for at least 1 second and select the “rezero sensor” button. Pull the device slowly by the hook for about 5 seconds, and then stop pulling. Measure the average acceleration and force during at least a five second period. Attempt to keep the acceleration value close to 0 m/s^2 as well a slope close to 0 for the force while pulling. This average force is the value of the kinetic friction force f_k designated by μ (-0.353 N on the first attempt).

ACTIVITY 3 - METHODS FOR MEASURING KINETIC FRICTION

10. Now that you have explored the phenomena and seen what the data looks like, you can start thinking about the main experiment. The question that we want to answer is:

Is there a statistically significant difference between the kinetic friction measured using Method A versus Method B?

To answer this question, you will perform multiple (up to you how many you do) method A and method B measurements of the kinetic friction, and for each you should record data in Excel, then use Excel tools to convert your data into the final quantity that you are looking for. Do not forget to regularly zero the force sensor.

In the end, you will want to have two columns like this (besides your measured data):

Method A or B	Average Kinetic friction
A/B	#

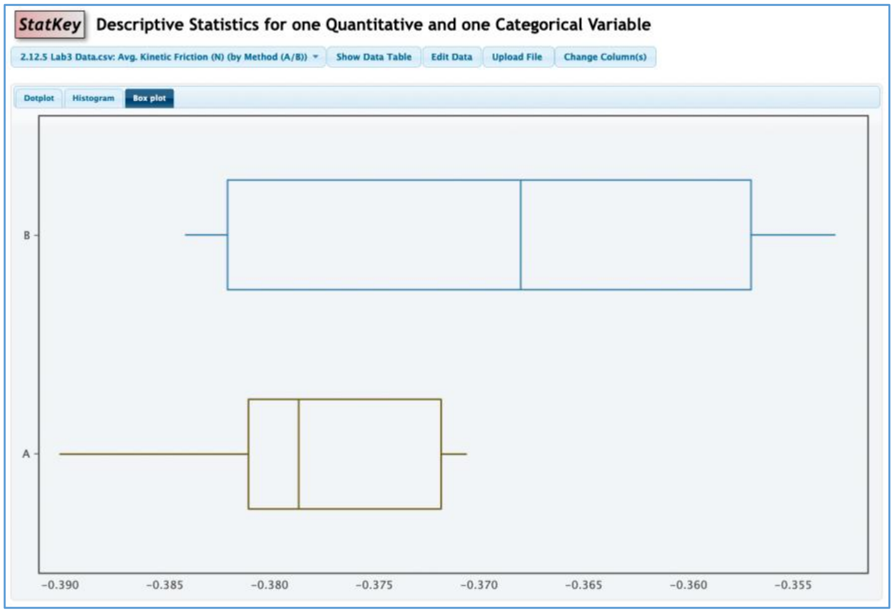
Do not record/evaluate experimental uncertainties in measurements. The IOLab is a very sensitive instrument and most of the uncertainties are coming from human errors or from natural variability on the table, etc. We will evaluate "statistically significant" by visualizing the data using StatKey.

Perform your designed experiment and record all your data in Excel. Save as a .cvs file. Go to StatKey, go to "One quantitative and One Categorical Variable" and upload your data using the "upload file" button. Create a boxplot.

Take a screenshot and upload the boxplot with the statistic on the left.

Graded on correctness. See videos on how to use StatKey and csv https://phys211.courses.science.psu.edu/the-boxplot-and-statkey .

Method (A/B)	Avg. Kinetic Friction (N)
A	-0.39
A	-0.381
A	-0.3718
A	-0.3786
A	-0.3706
B	-0.353
B	-0.384
B	-0.382
B	-0.368
B	-0.357



Summary Statistics

Statistics	A	B	Overall
Sample Size	5	5	10
Mean	−0.378	−0.369	−0.374
Standard Deviation	0.0078	0.014	0.012
Minimum	−0.39	−0.384	−0.39
Q_1	−0.38	−0.38	−0.38
Median	−0.38	−0.37	−0.38
Q_3	−0.37	−0.36	−0.37
Maximum	−0.3706	−0.353	−0.353

11. Analyze your data, make sense of it and draw conclusions to answer the question above. Write down any notes here. Make sure you explain how you are accounting for outliers if they are any.

	Inadequate	Adequate	Good
Is able to identify a pattern in the data	The pattern described is irrelevant or inconsistent with the data	The pattern has minor errors or omissions.	The patterns represent the relevant trend in the data. When possible, the trend is described in words.

There is not a statistically significant difference between the mean f_k values measured from Methods A and B. The magnitude of the mean f_k value from Method A (0.378 N) was just about 0.009 N greater than the magnitude of the mean f_k value from Method B (0.369 N), and both measured forces were in the negative y-direction. This is a difference of less than 3% between the mean values of both methods.

Additionally, the direction of the friction depends on how the axis is set, so it is important to compare magnitudes (especially if the forces had opposite signs).

Forrest Moulin

A MODEL FOR KINETIC FRICTION – PART 2

INTRODUCTORY INSTRUCTIONS

This lab will be graded using scientific ability rubrics. To help you know what we expect, the rubrics have been included along with the instructions for each question.

<u>Lab goals:</u> In this lab, you will design an experiment to determine the relationship between kinetic friction and mass of the object. You will also determine the coefficient of kinetic friction of the IOLab on a surface of your choice.

<u>Equipment available:</u> You will need the IOLab with computer/software and a horizontal surface (always use the same one!). You may need the “hook” attachment and a small piece of string to pull the IOLab. You will also need coins, pens or other small objects and tape in order to change the mass of the IOLab.

<u>Documents and videos needed.</u>

- We have multiple pages to read in the course content about this lab. These pages include videos instructions on how to use StatKey for two quantitative variables. In this lab, we will encounter for the first time the notion of the “best fit” line.

<u>Phenomenon to Observe:</u> When two objects in contact move relative to one another, the atoms at the interface interact electrically to create a force that resists the motion. This force is called kinetic friction and we know that it is always in the direction opposite to motion parallel to the interface.

Predicting the value of the friction force from the starting principles of material science and electromagnetism is still an open problem in physics. It is a very hard and complex phenomenon in surface dynamics. It turns out that the most important variable that determines the friction is the normal force which usually depends on the mass of the object on top. The properties of the surface can be all encoded into a coefficient of kinetic friction which must be determined case by case.

In this lab, you will need to find ways to measure correctly the value of the kinetic of friction and the value of the mass of the IOLab. By changing the mass of the IOLAB but keeping the surface the same, we can determine the relation between kinetic friction and mass.

<u>Variables</u>:

- Independent variable: mass of the IOLab + coins…
- Dependent variable 1: measured kinetic friction
- Dependent variable 2: measured kinetic friction by an alternative method?
- Controlled variables. Surface on which IOLab slide, temperature of the room or surfaces, etc..

Both dependent and independent variables are **quantitative variable** (they could be any numbers).

MASS DEPENDENCE OF KINETIC FRICTION

1. How does the kinetic friction depend on mass?

Describe how you will attempt to answer this question. You will want to measure the kinetic friction while varying the mass of the IOLab. But how will you do that in practice? Will you choose Method A or Method B of the previous Lab to measure the kinetic friction? How will you vary the mass of the IOLab? How many times will you measure the kinetic friction for each different mass? Make sure that you are clear on how to proceed.

For changing the mass of the IOLab, we recommend to tape additional objects (coins, pens, …) to the IOLab in a way that does not hinder the measurement of the kinetic friction. You also want to attach objects heavy enough for better results, but do not go too much over a total mass of 0.4kg, IOLab included.

	Inadequate	Adequate	Good
Is able to describe how to use available equipment to make measurements	All chosen measurements can be made, but no details are given about how it is done.	All chosen measurements can be made, but the details of how it is done are vague or incomplete.	All chosen measurements can be made and all details of how it is done are clearly provided.

I will use Method B from the previous lab, pulling the device on the surface in the negative y-direction at constant velocity for at least 5 seconds. For Method B1, I will use the hook to measure the gravitational force of the IOLab device by itself and then conduct the pulling experiment. On Methods B2-5, I will use the hook to measure the gravitational force of the IOLab with items taped to the top of the IOLab then conduct the pulling experiment:

- B2: IOLab + AirPods case
- B3: IOLab + AirPods case + two sharpies
- B4: IOLab + AirPods case + usb-c adapter
- B5: IOLab + AirPods case + two sharpies + usb-c adapter

To ensure that the mass does not exceed 0.4 kg in each case, I will steadily hold the device in the air by the hook, use the statistical tool to take measurements, and divide the average force by the average acceleration measured by the force/acceleration sensors on the y-axis ($\Delta t \geq 5$ s). Finally, I will calculate the average kinetic friction of three pulls for each mass and record the normal force ($n = F_g$ on level surface) and average kinetic friction force as quantitative variables in Excel.

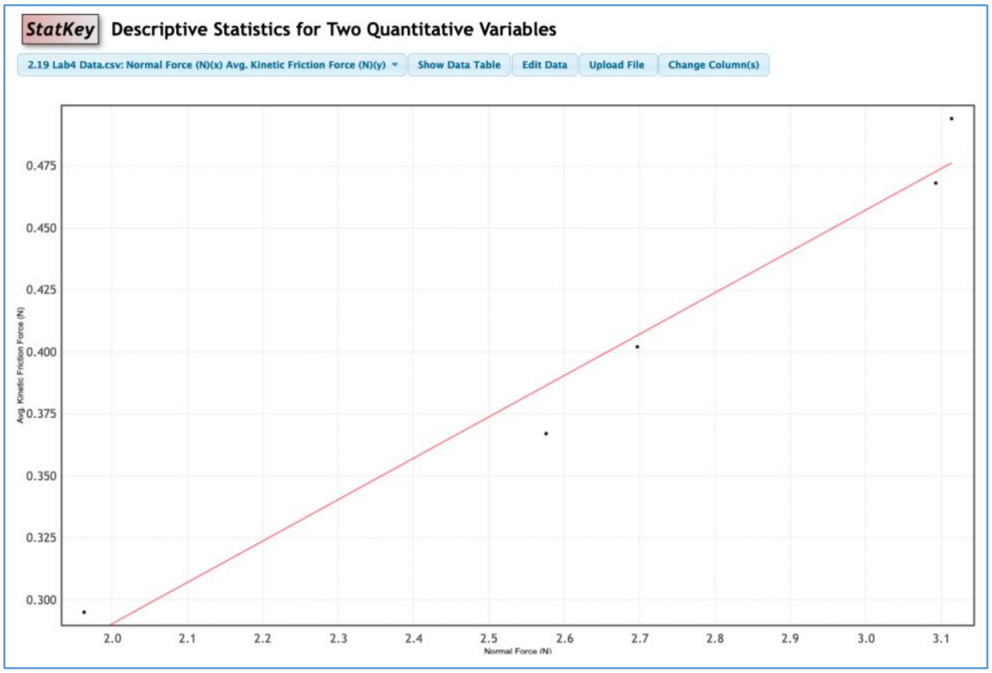
2. Perform your designed experiment and record all your data in Excel. Save as a .cvs file.

This is an experiment with two quantitative variables. We will use the “two quantitative variables” option in StatKey. The data will be represented as a dot plot where each data point appears as a dot in a x-y plane. We will use the **correlation** statistic to determine how strongly two quantities are correlated. We will also use the slope and intercept of the regression line to quantify the correlation assuming that it is linear (a straight line). See video and notes in the course content webpage.

Go to StatKey, go to “two quantitative variables” and upload your data using the “upload file” button. Click on “show your regression line”.

Take a screenshot and upload your graph here (with the statistics on the left included).

Graded on correctness.



Summary Statistics Switch Variables

Statistic	Normal Force (N)	Avg. Kinetic Friction Force (N)
Mean	2.689	0.405
Standard Deviation	0.470	0.080
Sample Size	5	
Correlation	0.983	
Slope	0.167	
Intercept	−0.043	

Scatterplot Controls

☑ Show Regression Line

Method	Normal Force (N)	Avg. Kinetic Friction Force (N)	Mass (kg)
B1 avg	1.963	0.295	0.201
B2 avg	2.576	0.367	0.264
B3 avg	2.697	0.402	0.276
B4 avg	3.093	0.468	0.319
B5 avg	3.114	0.494	0.320

3. StatKey gives you the slope and intercept of the regression line fitting your data. What is the slope? Analyze your data and make sense of it. Write down any notes here. Estimate the size of the errors if you can. Make sure you explain how you are accounting for outliers if they are any.

	Inadequate	Adequate	Good
Is able to identify a pattern in the data	The pattern described is irrelevant or inconsistent with the data	The pattern has minor errors or omissions.	The patterns represent the relevant trend in the data. When possible, the trend is described in words.

- The slope of the data is 0.167, represented by the regression line.
- The graph shows a sample size of 5, since there are five masses correlating with the average kinetic friction force from the three attempts for each mass.
- Correlation is 0.983, which is very close to 1.
- The intercept is -0.043, which is very close to 0.
- Average kinetic friction force values for B2 and B5 are further away from the correlation line, but they do not seem to be outliers.
- The change in normal force of B1-B5 was not incremental since each item added has a distinct mass.

4. Use the fit to determine physical data. So now let us assume a model of friction where $f_k = \mu_k n$. Can you determine the coefficient of kinetic friction μ_k from the data? What does the intercept mean (if anything)?

See course content on "fitting data". Graded on correctness.

The regression line is also known as the line of best fit. Instead of using the mass as a quantitative variable, I chose to place the normal force on the x-axis and the kinetic friction force on the y-axis (mass is directly correlated with the normal force on a level surface: n = mg). This allowed me to quickly find μ_k, the friction coefficient from the slope (μ_k= f_s/n = 0.167).

The intercept appears to be the y-intercept, which is the average kinetic friction force value where the normal force and mass equal 0 N. Since the correlation is not exactly 1, the best fit line does not intersect with the origin.

5. Based on your data, identify shortcomings of the experiment and what action you should take next to improve your conclusions.

	Inadequate	Adequate	Good
Is able to identify the shortcomings in an experiment and suggest improvements.	The shortcomings are described vaguely and no suggestions for improvements are made.	Not all aspects of the design are considered in terms of shortcomings or improvements.	All major shortcomings of the experiment are identified and reasonable suggestions for improvement are made.

The correlation of 0.983 was a promising result. However, during the experiment there were some obvious shortcomings that affected the results. First, when pulling the hook, I did not use a string. As a result, the angle of the pull might not have been parallel to the surface, which could have affected the kinetic friction force measured by the device. Second, the data set was relatively small, and having a larger sample could have improved the outcome.

Additionally, the device was not pulled at a perfectly constant velocity; it was not pulled in a completely straight line and the speed was not entirely constant. There were also factors that could have impacted the data, such as the cleanliness of the surface and its angle with respect to the ground. Lastly, while recording the mass of the device and different combinations of items, I was unable to hold it perfectly still. Thus, the device may have swung from side to side or accelerated up and down as I tried to hold it still. By improving these errors, it is likely that I would have recorded a better correlation between mass and kinetic friction force.