AP Physics Lab #5: Determination of the Coefficient of Friction (Big Idea 3)

3.A.3.1: The student is able to analyze a scenario and make claims (develop arguments, justify assertions) about the forces exerted on an object by other objects for different types of forces or components of forces.

3.C.4.2: The student is able to explain contact forces (tension, friction, normal, buoyant, spring) as arising from interatomic electric forces and that they therefore have certain directions.

In this investigation, you will use three different methods to determine the coefficient of friction between a block of wood and an aluminum plane. You will drag the block with a force sensor, slide a block down an incline, and pull a block across a horizontal surface using a modified Atwood system. As a result, you should be able to draw free-body diagrams, use force sensors, and experimentally determine the coefficient of friction between two surfaces. You should be able to design and perform an experiment to determine the coefficient of friction between a surface and an object undergoing acceleration.

Coefficient of Friction Pre-Lab:

Friction is a contact force that opposes the motion of an object. Generally, if an object is moving, friction will act in the opposite direction of the object's motion, thereby making it more difficult to move the object. In some cases, frictional force can allow an otherwise stationary object to move. For example, when you carry a stack of two books across a room, it is the friction between the top and bottom book that allows the top book to move in concert with the bottom book. If friction was not present, then the top book would remain stationary and fall behind as you carry the bottom book across the room. Frictional resistance to the relative motion of two solid objects is usually proportional to the force which presses the surfaces together as well as the roughness of the surfaces. Since it is the force perpendicular (⊥) or "normal" to the surfaces which affects the frictional resistance, this force is typically called the "normal force" and designated by F_N. The frictional resistance force may then be written: $F_f = \mu F_N$, where the ratio between the friction force and the normal force is called the coefficient of friction (μ): $\mu = F_f/F_N$.

P1. When an object is pulled across a rough horizontal surface at a constant speed, generally there are only four forces acting on the object. Sketch and label a free-body diagram for this scenario.

P2. In terms of Newton's second law, ΣF = ma, state the sum of forces for the x- and y-direction of your free-body diagram in P1.

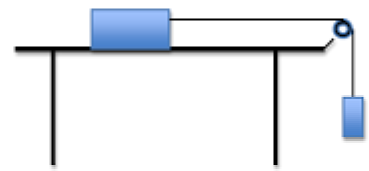
P3. When an object slides down a rough incline on its own accord at a constant speed, generally there are only four forces acting on the object. Sketch and label a free-body diagram for this scenario.

P4. In terms of Newton's second law, ΣF = ma, state the sum of forces for the parallel and perpendicular directions of your free-body diagram in P3.

P5. When an object is pulled by a string across a rough horizontal surface, generally, there are only four forces acting on the object. Sketch and label a free-body diagram for this scenario.

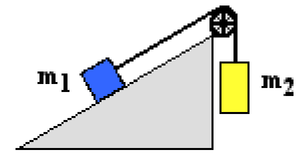
P6. In terms of Newton's second law, ΣF = ma, state the sum of forces for the x- and y-direction of your free-body diagram in P5.

P7. Compare and contrast the free-body diagrams of an object sliding across a horizontal surface with a constant speed and to one that accelerates across a surface.



P8. Suppose the object is now pulled by a string connected to a weight hanging over a pulley (i.e., modified Atwood machine), as shown in the figure to the right. Sketch and label a free-body diagram for this scenario recognizing that there are two objects that make up the system.

P9. In terms of Newton's second law, $\Sigma F = ma$, state the sum of forces for the x- and y-direction of your free-body diagram in P8.



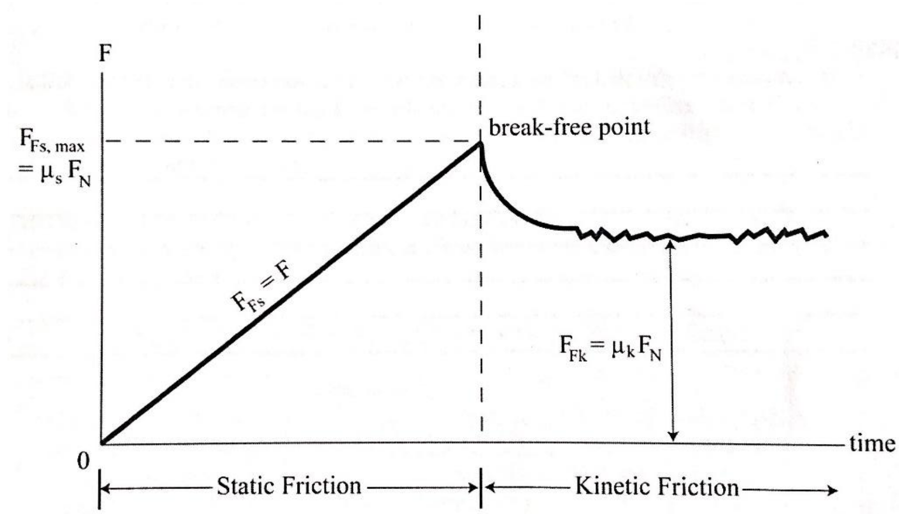
P10. Suppose the object is now pulled up an incline by a string connected to a weight hanging over a pulley (i.e., modified Atwood machine on an incline), as shown in the figure to the right. Sketch and label a free-body diagram for this scenario recognizing that there are still two objects that make up the system.

P11. In terms of Newton's second law, $\Sigma F = ma$, state the sum of forces for the parallel (∥) and perpendicluar (⊥*)* directions of your free-body diagram in P10.

Coefficient of Friction Lab:

Materials: friction block, string, hanging mass set, timer, electronic balance, aluminum incline, inclinometer on Smart phone, LabQuest 2 interface, Logger Pro (optional), Lab Quest App (optional) meter stick, low friction pulley, video analysis of choice (optional).

The most common way of measuring friction involves conducting a drag test. Automobile accident investigators often conduct drag tests at the scene of an accident in order to determine the coefficient of friction between the road surface and tires. Investigators typically use an 18-kg box with a layer of tire tread attached to the bottom of the box. The sled is dragged at a constant speed, and a force meter is used to determine the frictional force between the two surfaces in contact. Investigators then compare the frictional force to the normal force exerted by the road surface. In this case, the normal force is equal to the coefficient of friction between the two surfaces. Frictional force and coefficients of friction may be determined in the lab for any two surfaces using similar methods. For example, in order to find the coefficient of friction between two pieces of wood, one block of wood may be dragged at a constant speed with a force probe across another wooded surface. The experiment is most effective if the force probe is connected to a computer or LabQuest interface that provides a real-time graph of force versus time. If the block begins from rest, the graph will show an increasing force applied to the block. The force will peak just as the block begins to move and then it will drop to a lower force. The peak represents the static frictional force- the force that must be overcome in order to start moving the object. Static friction is always greater than kinetic friction. Kinetic friction is the force that must be applied to an object to keep the object moving at a constant velocity.



Part 1: Measuring the Coefficient of Friction; Question: *How can I measure the coefficient of friction (both static and kinetic) between a block of wood and an aluminum surface, or another surface of my choice? How will the frictional force change if I vary the normal force on the block by incrementally increasing the mass?*

Q1. Plan out your experiment and then design a table suitable for your anticipated data set. You may explore surfaces other than the aluminum track. Do not forget that you will need to vary the normal force on the block by incrementally increasing the mass. Plan on numerous trials for each mass increment to ensure accuracy.

Q2. Include a print-out or picture in your lab book of one force versus time graph that you feel best exemplifies your data set. On the graph, label all areas of interest (F_{sf}, F_{kf}, etc.). Underneath the graph, briefly explain each labeled area of interest.

Q3. Create a detailed graph of the static friction versus force normal. Draw a best-fit line. On the same graph, also plot the kinetic friction versus force normal and draw a best-fit line.

Q4. What is the significance of the slope for each line? Your answer should include the equations for each line.

Part 2: Measuring the Coefficient of Friction on an Incline; Question: *How can I measure the coefficient of static friction of an object in motion?*

Q5. Secure a mass of your choice to the block using a small piece of tape. Create a data table suitable for this part of the investigation. You may use the compass app on your Smart phone to determine the angle (ϴ). Conduct numerous trials to find the average angle at which the block/mass slides.

Q6. Referring back to your free-body diagram for P3, use the data collected to calculate the coefficient of static friction between the block and the aluminum track. As always, be sure to include a FBD and sum the forces.

Q7. The average angle you determined was used to calculate the coefficient of static friction. Propose an explanation that could relate this angle with the coefficient of kinetic friction.

Part 3: Coefficient of Friction of an Accelerating Object; Question: *How can I design an experiment to measure the coefficient of friction for an accelerating object?*

Q8. Design, describe, and conduct the investigation. Show all calculations and include a data table for your experiment. This is a significant component of the lab write-up, so please be detailed in your response.

Q9. You have experimentally determined the coefficient of friction between two surfaces using three independent methods. How do the results from each method compare to one another? The accepted values for maple wood on aluminum are: $\mu_{sf} = 0.3$ and $\mu_{kf} = 0.2$.

Please self-assess your lab report using the STEM Journal rubric/checklist.

Please note you should make a claim for each part of the lab.

A.R.M.S.