Lesson Title	Investigation of Static and Kinetic Friction Coefficients
Length of Lesson	1.5 hours
Created By	Justin Warren
Subject	Physics
Grade Level	11-12
State Standards	1 d, 2 a, b, c
DOK Level	DOK 2
DOK Application	Collect and display, interpret
National Standards	9-12: B
Graduate Research Element	When sizing a projectile for a barrel, the diameter must be large enough to ensure no gases escape around the projectile but small enough to prevent damage to the projectile caused by excessive friction while it travels through the barrel.

Student Learning Goal:
Students will understand what the physical meaning of both the static and kinetic coefficients of friction are as well as what they can infer from high and low friction coefficient values. They will also understand how lubrication affects both coefficients of friction.

Physics: 1. Apply inquiry-based and problem-solving processes and skills t organize investigations: d) Organize data to construct graphs, draw conclusions, and make inferences. 2. Develop and understanding of concepts related to force and motion: a) Use inquiry to investigate and develop an understanding of the kinematics and dynamics of physical bodies, b) Analyze, describe, and solve problems by creating and utilizing graphs of one-dimensional motion, c) Analyze real-world applications to draw conclusions about Newton's three laws of motion

National Science Education Standards of Content 9-12
B (Physical): Motions and Forces: Objects change their motion only when a net force is applied. Laws of motion are used to calculate precisely the effects of forces on an object. The magnitude of the change in motion can be calculated using the relationship F=ma, which is independent of the nature of the force. Whenever one object exerts force on another, a force equal in magnitude and opposite in direction is exerted on the first object.

Materials Needed (supplies, hand-outs, resources):
A 6in length piece of a 4in x 4in wooden post both with an eye bolt inserted perpendicular to one end, three of the long sides of the block will have either a thin aluminum plate, a thin sheet of rubber, or a thin nylon plate attached to it using super glue or epoxy, a Pasco or Verneer force sensor (a spring scale will also work), a 10in x

24in piece of plywood, lubricant (diluted dish soap, cooking oil, etc…), a lubricant of high molecular weight is preferred to slow evaporation

Lesson Performance Task/Assessment:
The students will work in groups of 2: one to handle data acquisition and the other to pull the wooden blocks. There are 4 distinct parts of this lesson

Part 1: Determine Static and Kinetic Coefficients of Friction with Dry Floor

The students will perform the following procedure for all 4 surfaces of the wooden block. The force sensor (or spring scale) will be attached to the eye bolt of the block, and the student will hold the force sensor preparing to begin pulling. See Figure 1 to view a block ready to pull. Note that the Pasco force sensor is shown and that the block used in this lesson will be different. The lesson idea is that same no matter what sort of block you use or what brand force sensor. You could even use a less costly spring scale.

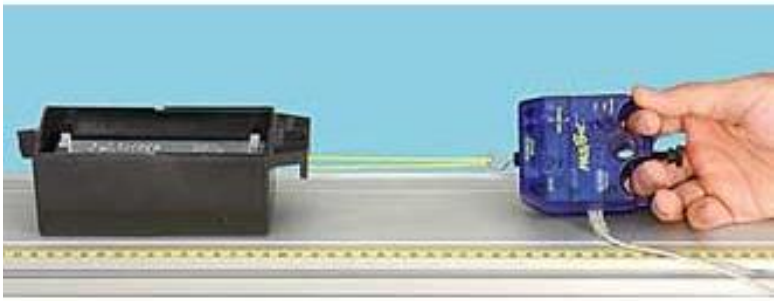

Figure 1. Friction block setup ready to pull
(http://www.pasco.com/prodCatalog/EX/EX-9939_sliding-friction-experiment-pasport/)

The student in charge of pulling the block will then very slowly increase the force with which they are pulling the block until it just starts to move. The pulling student will then continue to pull the block at a constant velocity (must try not to accelerate or decelerate which would introduce inertial forces and would skew results) for about 12in of total block travel. It is important that the pulling student pull parallel with the floor and not at an angle which would skew the results by adding a vertical component to the force. Figure 1 above shows the correct pulling angle.

Meanwhile, the data acquisition student will log the force data using the Pasco or Verneer software. If using a spring scale the student will manually monitor and record spring scale readings, and then input them into a spreadsheet program. The peak force corresponding to the initial block movement, f_s, will be associated with the coefficient of static friction, μ_s, which can be calculated using Equation 1.

$$f_s = \mu_{static} \cdot F_{normal} \quad (1)$$

where F_{normal} is the weight of the block (its mass times the gravitational constant). The constant force corresponding to pulling the block at a constant velocity, f_k, will be associated with the coefficient of kinetic friction, μ_k, which can be calculated using Equation 2.

$$f_k = \mu_{kinetic} \cdot F_{normal} \quad (2)$$

Knowing these forces, the mass of the blocks, and the gravitational constant the students can then calculate the coefficients of static and kinetic friction between all four block surfaces and the floor material. A sample of read out from the Pasco force sensing software package is shown in Figure 2. Note the peak and steady force levels.

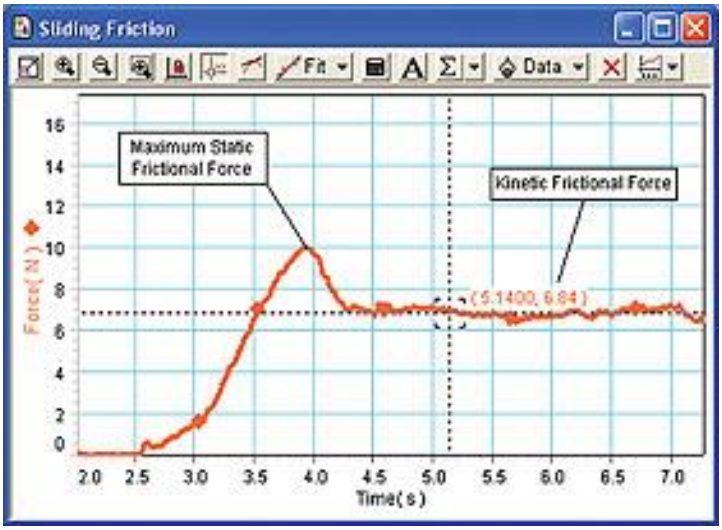

Figure 1. Force sensor read out
(http://www.pasco.com/prodCatalog/EX/EX-9939_sliding-friction-experiment-pasport/)

As stated earlier, the students will perform pulls for all 4 sides of the wooden block. This means they should have a total of 4 pulls resulting in 8 coefficients of friction (a static and kinetic coefficient for each pull). The following parts follow the same procedure as the first but the differences will be discussed.

Part 2: Determine Static and Kinetic Coefficients of Friction with Dry Plywood

During Part 2 the students will repeat all the steps of Part 1 with one difference. This time the block will be pulled across the 10in x 24in piece of plywood. Here the coefficients of friction they calculate will be different. This is because coefficients of

friction are relative values. If one of the surfaces is changed, it is very likely that the coefficient of static and kinetic friction will change as well. Again, the students should have calculated 8 coefficients of friction in Part 2 just as they did in Part 1.

Part 3: Determine Static and Kinetic Coefficients of Friction with Lubricated Floor

During Part 3, students will repeat all the steps of Part 1 with one difference. This time they will lightly lubricate a 6in x 18in portion of floor and the block sides before pulling the block. It is important to stress that only a small amount of lubrication is necessary (a thin film) and that the students are in charge of cleaning up after the lesson is over. The students should have calculated 8 coefficients of friction in Part 3.

Part 4: Determine Static and Kinetic Coefficients of Friction with Lubricated Plywood

During Part 4 the students will repeat all the steps of Part 3 with one difference. This time the block will be pulled across the lightly lubricated a 6in x 18in portion of the 10in x 24in piece of plywood. Here again the coefficients of friction they calculate will be different because one of the relative surfaces has changed. The students should have calculated 8 coefficients of friction in Part 4.

Lesson Relevance to Performance Task and Students:
The students will understand what static and kinetic friction are as well as how to interpret coefficients of static and kinetic friction for relative surfaces. They will also physically investigate the effects of lubrication on coefficients of friction. This will allow them to better understand why lubrication is important in many engineering applications.

Anticipatory Set/Capture Interest:
The class will be shown a YouTube video of the SR-71 Blackbird. They will be told its max speed was 2,500mph (altitude dependent) and that its titanium fuselage elongates 6in once it reaches that max speed! How is this possible? As a clue, they will be told that the pilot could bake a cake in his lap because the cockpit temperature reached 250^{o}F. If they haven't guessed already, announce that Friction was the culprit! Yes, friction between the plane and the air traveling at Mach 3.3 around the plane heated the fuselage to over 500^{o}F!

Guided Practice:
The instructor will discuss the lesson procedures and show a sample block pull to emphasize constant velocity pulling and pulling parallel to the surface.

Independent Practice:
The students will carry out the entirety of the lesson on their own without direct instruction from the instructor. The instructor will move around the room during the lab in order to answer any questions or offer advice if a group is obviously performing the lesson incorrectly.

Remediation and/or Enrichment:
It is expected that the relatively simple procedure and relationships involved in this lab will require a very limited amount of remediation if any.

For enrichment, have the students consider why lubrication lowers the coefficient of friction. Have them search online for explanations.

Check(s) for Understanding:
The student will be required to discuss the difference between the coefficients of static and kinetic friction. More importantly they will discuss how the coefficients of friction can be thought of as relative values that depend on the combination of surfaces involved. They will also be asked to discuss the effect of lubrication on the coefficients of friction.

Closure:
Following the lab, the instructor will lead a short discussion of where coefficients of friction are relevant in everyday life such as the grease inside a door handle, cooking in a frying pan, or taking a corner fast in a car. Consideration of frictional forces is also relevant to my hypervelocity research. If a projectile diameter is too large for a barrel, the frictional forces can greatly erode the projectile before it leaves the barrel. This consequently will affect the impact characteristics.

Here are a few provocative questions to ask the students after the lesson:

- Why do you think would happen to a running car engine without oil?
- How could you measure frictional force indirectly (think of temperature)?
- What explanation do you have for why the coefficients of friction were different for the different surfaces?

Possible Alternate Subject Integrations:
Data acquisition and manipulation

Teacher Notes:
Make sure students don't get lubricant everywhere

Always lubricate the same side of plywood so as not to ruin the pristine side for future lessons

The lubricated section can be eliminated in case of time restrictions