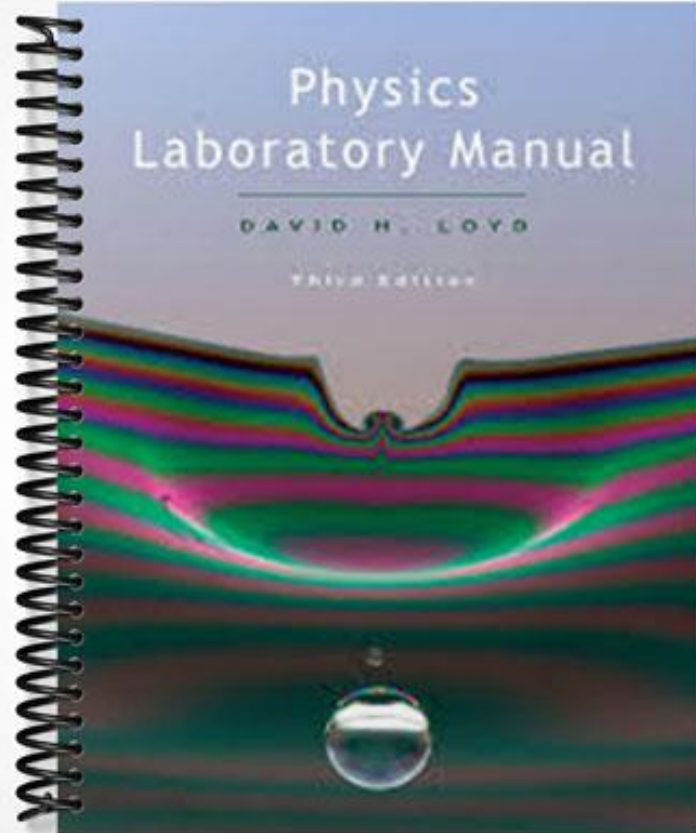


# SOLUTIONS MANUAL



# Coefficient of Friction Using a Force Sensor and a Motion Sensor

## OBJECTIVES

- Investigate the coefficient of static friction between a felt-covered wood block and a metal track using a force sensor to measure the force needed to move it from rest.
- Investigate the coefficient of kinetic friction between a felt-covered wood block and a metal track by determining the acceleration of the block for different applied forces.

## EQUIPMENT LIST

- Rectangular friction block with hook, 1.22 m track, pulley with clamp
- Computer, interface device, *DataStudio* software, force sensor, motion sensor

## THEORY

**Friction** is a resisting force that acts along the tangent to two surfaces in contact when one body slides or attempts to slide across another. **Normal force** is the force that each body exerts on the other body, and it acts  $90^\circ$  to each surface. The frictional force is directly proportional to the normal force.

There are two different kinds of friction, static friction and kinetic friction. **Static friction** occurs when two surfaces are still at rest with respect to each other, but an attempt is being made to cause one of them to slide over the other one. Static friction arises to oppose any force trying to cause motion tangent to the surfaces. The static frictional force  $f_s$  is given by

$$f_s \leq \mu_s N \quad (\text{Eq. 1})$$

where  $N$  stands for the normal force between the two surfaces, and  $\mu_s$  is a constant called the **coefficient of static friction**. The meaning of Equation 1 is that the static frictional force varies in response to applied forces from zero up to a maximum value given by the equality in that equation. If the applied force is less than the maximum, then the frictional force that arises is equal to the applied force, and there is no motion. When the applied force is equal to the maximum, the object will begin to move, and static friction conditions are no longer valid. The value of  $\mu_s$  is approximately independent of  $N$ .

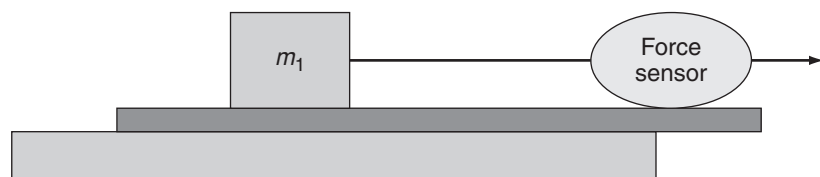


Figure 7A-1 Force sensor measuring minimum force needed to move the block.

Figure 7A-1 shows the arrangement of a force sensor applied to a block to measure the minimum force needed to move a block. As the block moves, the force read on the force sensor is equal in magnitude to the value of  $f_s$ , the force of static friction.

**Kinetic friction** occurs when two surfaces are moving with respect to each other. It is characterized by a constant  $\mu_k$  called the **coefficient of kinetic friction**. The kinetic frictional force  $f_k$  is given by

$$f_k = \mu_k N \quad (\text{Eq. 2})$$

where  $N$  is again the normal force. Equation 2 states that the kinetic frictional force is a constant value any time the object is in motion. In fact, the coefficient of kinetic friction varies somewhat with speed. It is assumed for this laboratory that at the slow speeds used,  $\mu_k$  does not depend upon speed. To a good approximation both coefficients seem to be independent of the apparent area of contact of the two surfaces.

In Figure 7A-2 a block of mass  $m_1$  on a metal track is shown attached by a string over a pulley to a mass  $m_2$ . The mass  $m_2$  is chosen so that if the block is held and then released, the block and mass  $m_2$  will accelerate. Assuming the pulley can be considered massless and frictionless, the tension  $T$  in the string is the same on either side of the pulley. The block will accelerate to the right, and mass  $m_2$  will accelerate downward, with an acceleration of magnitude  $a$ . The normal force  $N$  equals  $m_1 g$ , the weight of the block. The equations that describe the summation of forces on each of the masses are given by

$$m_2 g - T = m_2 a \quad (\text{Eq. 3})$$

$$T - \mu_k m_1 g = m_1 a \quad (\text{Eq. 4})$$

Combining Equations 3 and 4 gives

$$m_2 g - \mu_k m_1 g = (m_1 + m_2) a \quad (\text{Eq. 5})$$

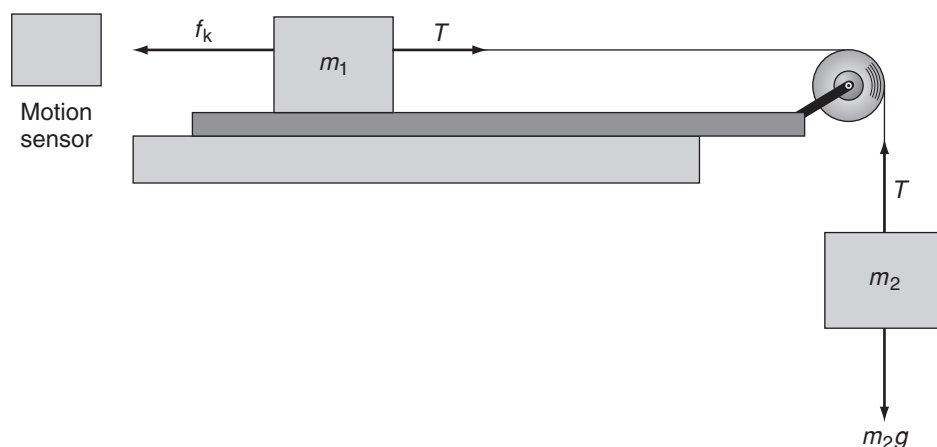


Figure 7A-2 Force applied to a block of mass  $m_1$  on a horizontal plane by mass  $m_2$ .

## EXPERIMENTAL PROCEDURE AND CALCULATIONS

### Static Friction with a Force Sensor

1. Determine the mass of the block with the balance and record it as  $m_1$  in the Static Friction Data and Calculations Table under 0.000 kg added.
2. Remove any stops that are on the 1.22 m track. Place the track on the laboratory table and level it.
3. Place the block on the track with the felt side down. Tie a loop in each end of a light string, attach one loop to the hook in the block, and attach the other loop to the force sensor.
4. Connect the *Science Workshop* interface to the computer and turn on the computer and the interface. Plug the lead from the force sensor into the first analog channel of the interface device.
5. Open the program *DataStudio* on the computer. Click *Create Experiment* and drag the *Force Sensor* icon to the first analog channel on the *Interface* icon. Press the *Tare* button on the force sensor to zero it.
6. Press the *Start* button and then slowly pull on the force sensor, which will pull on the block until it moves. Press the *Stop* button. Repeat this process two more times for a total of three measurements of the force at which the block begins to move. Drag the *Graph* icon to the first run to produce a graph of the force versus time. Drag the data runs from the other two measurements to the same graph.
7. Use the *Smart Tool* to determine the maximum value of the force for each of the three trials and record them as  $f_s$ , the static friction force, under the heading of 0.000 kg added in the data table. Print the graph.
8. Place a mass of 0.100 kg on top of the block and repeat Steps 6 and 7. Also repeat the same steps for mass of 0.200 kg on top of the block. In each case record the results as  $f_s$  in the data table, under the heading of 0.100 kg added and 0.200 kg added. Print each graph and close the *DataStudio* window. Save the data in the event future analysis is needed.
9. Determine the mean, standard deviation, and standard error for the three repeated measurements of the frictional force  $f_s$  for each of the three values of  $m_1$ . Record all of those values in the data table.
10. The normal force of the block is  $m_1g$ . Use that in Equation 1 to solve for an equation for the static coefficient of friction  $\mu_s$ . In that equation use the mean values of the frictional force to calculate three values of  $\mu_s$  for the three values of  $m_1$ . Record those  $\mu_s$  values, and then calculate and record the mean, standard deviation, and standard error for your measurements of  $\mu_s$ .

### Kinetic Friction with a Motion Sensor

1. Place the block ( $m_1$ ) on the track with the felt side down. Clamp the lightweight plastic pulley to the track. Tie a loop in each end of a light string, attach one loop to the hook in the block, and run the other loop over the pulley. Attach a mass ( $m_2$ ) to the loop over the pulley. Choose  $m_2$  to be just slightly greater than the minimum mass needed to accelerate  $m_1$  after it is held and then released. Record the value of  $m_2$  in the data table.
2. Place the motion sensor about 0.30 m from the end of the track that does not have the pulley attached. Plug the yellow lead of the motion sensor into Digital Channel 1 and plug the black lead into Digital Channel 2 of the interface device.
3. Open the program *DataStudio* on the computer. Click *Create Experiment* and drag the *Motion Sensor* icon to Digital Channel 1 on the *Interface* icon.
4. Have one lab partner place a mass of value  $m_2$  on the loop over the pulley while holding the block in place. Release the block and simultaneously click the *Start* button. Click the *Stop* button just before the block reaches the pulley and catch the block so that it does not hit the pulley. Repeat this process two more times for a total of three trials.
5. Drag the *Graph* icon to the velocity data of the first run. Use the cursor to select that portion of the data on the graph that appears to be linear. This will highlight that data in yellow. Click on the *Fit* icon and choose *Linear Fit* option. Print out the graph with the dialog box that includes the slope of the fit, which

is the acceleration  $a$  of the system. Repeat this process for the other two trials with these values of  $m_1$  and  $m_2$ . Record the three values of  $a$  for the three trials in the data table. Calculate the mean, standard deviation, and standard error for the values of  $a$  and record them in the data table.

6. Place a mass of 0.100 kg on top of the block and repeat Steps 4 and 5 using a value of  $m_2$  that will just accelerate the system when released. Record the values of the accelerations and their means, standard deviations, and standard errors in the data table.
7. Place a mass of 0.200 kg on top of the block and repeat Steps 4 and 5 using a value of  $m_2$  that will just accelerate the system when released. Record the values of the accelerations and their means, standard deviations, and standard errors in the data table.
8. Use the equation for  $\mu_k$  that you determined in Question 6 of the Pre-Laboratory to calculate three values of  $\mu_k$  from the mean values of the measured accelerations and the known values of  $m_1$  and  $m_2$  for each case. Record those three values, and then calculate and record the mean, standard deviation, and standard error for your measurements of  $\mu_k$ .

7A

**LABORATORY 7A** *Coefficient of Friction Using a Force Sensor  
and a Motion Sensor***PRE-LABORATORY ASSIGNMENT**

1. For kinetic friction, the direction of the frictional force on a given object is always opposite the direction of that object's motion. (a) True (b) False
2. Static friction is (a) always less than the applied force. (b) always greater than the applied force. (c) less than the applied force up to some maximum force. (d) equal to the applied force up to some maximum force.
3. The two coefficients of friction discussed in this laboratory are static ( $\mu_s$ ) and kinetic ( $\mu_k$ ). Describe the conditions under which each kind is appropriate. Generally, which of the two is larger?
4. Suppose a block of mass 25.0 kg rests on a horizontal plane, and the coefficient of static friction between the surfaces is 0.220. (a) What is the maximum possible static frictional force that could act on the block? \_\_\_\_\_N (b) What is the actual static frictional force that acts on the block if an external force of 25.0 N acts horizontally on the block? \_\_\_\_\_N Assume  $g = 9.80 \text{ m/s}^2$ . Show your work and explain both answers.
5. For the laboratory measurement of the static coefficient of friction the maximum value of the force measured by the force sensor is taken to be the value of  $f_s$  the frictional force. Describe why the maximum value of the force is the correct measurement.

6. Solve Equation 5 in the Laboratory Theory section for  $\mu_k$  in terms of the other quantities in the equation. Explain how the measurements in the laboratory will make use of the equation you have written to determine  $\mu_k$ .

7. Both types of coefficient of friction are dimensionless. Why is this true?

8. For either type of coefficient of friction, what is generally assumed about the dependence of the value of the coefficient on the area of contact between the two surfaces?

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Name

Section

Date

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Lab Partners

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7A

**LABORATORY 7A**

*Coefficient of Friction Using a Force Sensor  
and a Motion Sensor*

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**LABORATORY REPORT**

*Static Friction Data and Calculations Table*

<i>Added mass</i>	0.000 kg	0.100 kg	0.200 kg
$m_1$ (kg)			
$f_s$ Trial 1 (N)			
$f_s$ Trial 2 (N)			
$f_s$ Trial 3 (N)			
$\bar{f}_s$ (N)			
$(\sigma_{n-1})_{f_s}$ (N)			
$\alpha_{f_s}$ (N)			
$\mu_s$			
$\bar{\mu}_s =$	$(\sigma_{n-1})_{\mu_s} =$	$\alpha_{\mu_s} =$	



Kinetic Friction Data and Calculations Table

Added mass	0.000 kg	0.100 kg	0.200 kg
$m_1$ (kg)			
$m_2$ (kg)			
$a$ Trial 1 ( $\text{m/s}^2$ )			
$a$ Trial 2 ( $\text{m/s}^2$ )			
$a$ Trial 3 ( $\text{m/s}^2$ )			
$\bar{a}$ ( $\text{m/s}^2$ )			
$(\sigma_{n-1})_a$			
$\alpha_a$			
$\mu_k$			
$\bar{\mu}_k =$	$(\sigma_{n-1})_{\mu_k} =$	$\alpha_{\mu_k} =$	

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### SAMPLE CALCULATIONS

- $\mu_s =$
- $\mu_k =$

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### QUESTIONS

- The standard error of  $\mu_s$  is a measure of the uncertainty in your experimental value. Express it as a percentage of  $\mu_s$ . If that percentage is 5% or less the results are excellent, if 10% or less they are good, and if 20% or less they are fair. Based on these criteria, discuss your results and discuss any contributions to the uncertainty you might suggest.
- The standard error of  $\mu_k$  is a measure of the uncertainty in your experimental value. Express it a percentage of  $\mu_k$ . If that percentage is 5% or less the results are excellent, if 10% or less they are good, and if 20% or less they are fair. Based on these criteria, discuss your results and discuss any contributions to the uncertainty you might suggest.

3. To what extent do your data confirm the expectation that the coefficients of friction, both static and kinetic, are independent of the normal force? Describe what aspect of the data is evidence for your conclusion.

4. Do your data confirm the expectation that  $\mu_s \geq \mu_k$  within the uncertainties of the measured values of the two coefficients?

