

# LABORATORY III

## FORCES

The problems in this laboratory will help you investigate the effect of forces on the motion of objects. In the first problem, you will investigate the effects of forces on a sliding object. In the second problem, you will apply the force concept and the vector nature of forces to a situation in which nothing moves. The third and fourth problems investigate the behavior of the frictional forces.

### OBJECTIVES:

After successfully completing this laboratory, you should be able to:

- Make and test quantitative predictions about the relationship of forces on objects and the motion of those objects for real systems.
- Use forces as vector quantities.
- Characterize the behavior of the frictional force.
- Improve your problem solving skills.

### PREPARATION:

Read Serway & Vuille Chapter 4. Review Sections 3.1 and 3.2 regarding the properties of vectors. Review your lab journal notes about the behavior of an object sliding down an inclined track.

Before coming to lab you should be able to:

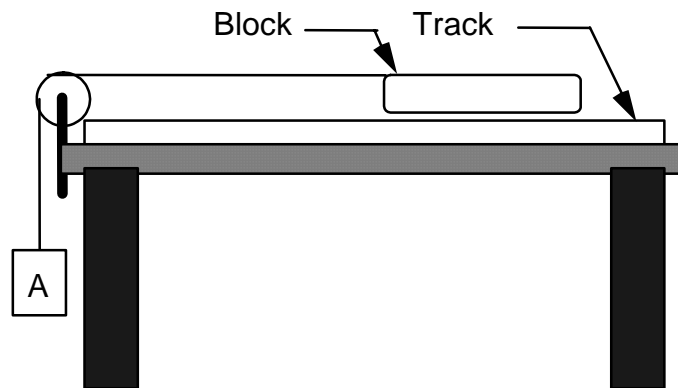
- Define and use sine, cosine and tangent for a right triangle.
- Recognize the difference between mass and weight.
- Determine the net force on an object from its acceleration.
- Draw and use free-body diagrams.
- Resolve force vectors into components and determine the total force from the components.
- Explain what is meant by saying a system is in "equilibrium."
- Write down the force law for a frictional force.

# PROBLEM #1: HOW SURFACES AFFECT THE KINETIC FRICTIONAL FORCE

You are helping a friend design a new game to use on the Midway at the Minnesota State Fair. The game is similar to shuffleboard -- players use a short stick to push a puck just hard enough so that it will travel along a level surface and fall into one of several holes. To construct the pucks your friend wants to use either natural wood, or felt covered wood. He has decided that the sliding surface will be aluminum. He needs to know which block surface (felt or wood) to use for the game. If there is too much friction, no one will ever get the puck into the holes. If there is too little friction, then the game will be too easy. He knows you are taking a physics course, so he asks you to help. To solve this problem, you devise an experiment to measure the kinetic frictional force between the block and the board.

## EQUIPMENT

A block is pulled along a level track as shown below.



For this lab you will have a block that has both a wood side and a felt side. You will also have a stopwatch, meter stick, string, pulley, aluminum track, mass hanger with a set of masses (for object A), a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).

## PREDICTION

Write an expression for the frictional force on the sliding block as a function of the mass hanging on the string (object A), the mass of the block, and the acceleration of the block.

## WARM-UP

Read: Serway & Vuille Chapter 4, Sections 4.1 to 4.6

1. Make a sketch the problem situation that is similar to the picture in the Equipment section. Draw and label vectors to indicate the direction of the velocity and the direction of the acceleration for both the hanging object A and the block. Also assign symbols to the “known” quantities in the problem: the mass of object A and the mass of the block.
2. Write down the principles of Physics that you will use to solve the problem. (Hint: Think about Newton’s laws of motion!) Will you need any of the principles of kinematics? Write down any assumptions you have made that are necessary to solve the problem and are justified by the physical situation. What quantities can you measure using the video analysis software?
3. Draw separate free-body diagrams of the forces on the block and the forces on object A after they start accelerating. Assign symbols to all of the forces, and define what they represent next to your diagram. For easy reference, it is useful to draw the acceleration vector for the object next to its free-body diagram. It is also useful to put the force vectors on a separate coordinate system for each object (force diagram). Remember that on a force diagram, the origin (tail) of all vectors is at the origin of the coordinate system.
4. For *each* force diagram (one for the block and another one for object A), write down Newton's 2nd law in both the x and y directions. It is important to make sure that all of your signs are correct. For example, if the acceleration of the block is in the positive direction, is the acceleration of object A positive or negative? Your answer will depend on how you define your coordinate system.
5. What special condition connects the acceleration of the block and object A? Relate the force of the string pulling on the block to the force of the string pulling on object A (assuming a "massless" string and “frictionless” pulley).
6. Write down an equation, from those you have collected in steps 4 and 5 above, which relates what you want to know (the kinetic frictional force on the block) to a quantity you either know or can find out (the acceleration of the block).
7. Now you have a new unknown (the force of the string on the block). Write down a new equation for this unknown which relates the force of the string on the block to the force of the string on object A. Again you have a new unknown (the force of the string on object A). Write down a new equation for this unknown which relates it to the acceleration of object A.
8. Write down a new equation that relates the acceleration of object A to the acceleration of the block. If you have generated no additional unknowns, you should have as many equations as unknowns.
9. Combine your equations from step 6 with algebra to write an expression for the kinetic frictional force on the block in terms of the mass of object A, the mass of the block, and the acceleration of the block.

**EXPLORATION**

For both surfaces in question (felt and wood), slide the block along the track. Make sure it slides smoothly. If it does not, try cleaning the surfaces.

Determine the length of string you should use to connect the block to the mass hanger holding masses (object A). Remember that you will want to take a video of the system while both objects are

accelerating (before object A hits the floor). Decide on a position where you will release the block that fits in the frame of the camera, and will give you enough data points for the motion.

Find a range of masses for object A that allows the block to accelerate smoothly across the track. Explore the different accelerations using a large range of masses. Try these masses for the two contact surfaces to be sure the block accelerates uniformly in both cases. Choose a range of masses that will give a smooth acceleration. You should use the same range of block masses for each surface.

Practice releasing the block from the position you determined and one of your chosen masses for object A. Determine how much time it takes for object A to hit the floor and estimate the number of video points you will get in that time. Are there enough points to make the measurement? Adjust the camera position, mass range of object A, or the release position/length of the string to give you enough data points. Be sure to check this for both surfaces of the block.

Write down a plan of how you will take your measurements. What will you use for a reference object to calibrate your video? Make sure that the plan will adequately check your prediction.

<b>MEASUREMENT</b>
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Carry out the measurement plan you determined in the Exploration section. You can change the mass of the block, the mass of object A, or the surfaces and determine if the frictional force behaves as you predict.

Make sure you measure and record the mass of the block and object A (with uncertainties). Repeat the necessary measurements using a different block surface.

Complete the entire analysis of one case before making videos and measurements of the next case. *Make sure each person in your group gets a chance to operate the computer.*

<b>ANALYSIS</b>
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Using VideoTOOL, determine the fit functions that best represent the position vs. time graphs for the sliding block in the x and y directions. How can you estimate the values of the constants of each function from the graph? You can waste a lot of time if you just try to guess the constants. What kinematic quantities do these constants represent?

Do the same for the velocity vs. time graphs in the x and y directions. Compare these functions with the position vs. time functions.

From each video, determine the acceleration of the sliding block (with uncertainty). Is the average acceleration different for the beginning of the video (when the object is moving slowly) and the end of the video (when the object is moving fast)? Before you begin any time consuming analysis, determine if the acceleration of the block is constant. If it is, you can use kinematic relationships to simplify your task. Decide on the minimum number of data points that you need to analyze in order to determine the acceleration accurately and reliably. Remember that it is not the purpose of this problem to find accelerations!

For each contact surface, use your predicted expression from the Warm-up and Prediction to calculate the kinetic frictional force with the appropriate units. Have you measured all of the

quantities that you need for this expression? If not, make sure you measure them before you leave the lab.

<p style="text-align: center;"><b>CONCLUSION</b></p>
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What does your data show about the effect of the contact surfaces on the kinetic frictional force? Did your results agree with your initial prediction? Why or why not?

Which surface (wood or felt) will you recommend to your friend? Why? Will one surface be more useful to the game at the State Fair? What are the limitations on the accuracy of your measurements and analysis?

## PROBLEM #2: FORCES IN EQUILIBRIUM

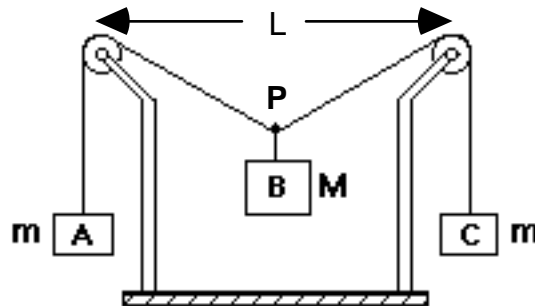
You have a summer job with a research group studying the ecology of a rain forest in South America. To avoid walking on the delicate rain forest floor, the team members walk along a rope walkway that the local inhabitants have strung from tree to tree through the forest canopy. Your supervisor is concerned about the maximum amount of equipment each team member should carry to safely walk from tree to tree. If the walkway sags too much, the team member could be in danger, not to mention possible damage to the rain forest floor! You are assigned to set the load standards.

Each end of the rope supporting the walkway goes over a branch and then is attached to a large weight hanging down. When the team member is at the center of the walkway between two trees, you need to determine how the sag of the walkway is related to the mass of the counterweights and the total mass of the team member with their equipment. To check your calculation, you decide to model the situation using the equipment shown below.

### EQUIPMENT

The system consists of a central object B (mass  $M$ ), suspended halfway between two pulleys by a string. The picture below is similar to the situation with which you will work. The objects A and C, which have the same mass ( $m$ ), allow you to determine the force exerted on the central object by the string.

You do need to make some assumptions about what you can neglect. For this investigation, you will also have a meter stick, two pulleys with two pulley clamps, three mass hangers, and a mass set to vary the mass of object B.



### PREDICTION

Write an equation for the change in the vertical displacement of the central object B in terms of the horizontal distance between the two pulleys ( $L$ ), the mass of object B ( $M$ ), and the mass ( $m$ ) of objects A and C.

Use your equation to sketch the expected graph of the vertical displacement of object B versus its mass ( $M$ ). When you are making your graph, consider what happens when  $M = 2m$ , and when  $M > 2m$ .

### WARM-UP

Read: Serway & Vuille Chapter 4, Sections 4.1 to 4.4. Review Chapter 3 Sections 3.1 and 3.2

1. Draw a picture of the setup similar to the one in the Equipment section (be sure to include the symbols for the horizontal distance  $L$ , and the masses  $m$  and  $M$ .) Label the angle that the string sags below the horizontal as  $\theta$  and the displacement of point P as " $d$ ". Use trigonometry to show how the vertical displacement ( $d$ ) of object B is related to the angle  $\theta$  and the horizontal distance  $L$ .
2. Draw separate free-body diagrams of the forces on objects A, B, C, and at point P. Assign symbols to all of the forces, and define what they represent next to your diagram. Check to see if any of these forces are related by Newton's 3rd Law (Third Law Pairs). It is also useful to put the force vectors on a separate coordinate system for each object (force diagram). Remember that on a force diagram, the origin (tail) of all vectors is at the origin of the coordinate system.
3. Write down the acceleration for each object. For *each* force diagram resolve all forces into their  $x$  and  $y$  components and write down Newton's 2nd law along each coordinate axis.
4. Solve your equations for the vertical displacement ( $d$ ) of object B in terms of the mass ( $M$ ) of object B, the mass ( $m$ ) of objects A and C, and the horizontal distance ( $L$ ) between the pulleys. Your final equation **should not** depend on angles. *Hint: Use definitions of trig functions (sine, cosine, and tangent) for a right triangle, and the Pythagorean Theorem for additional relationships.*
5. Use your equation to sketch the shape of the graph of the vertical displacement versus mass of object B.

### EXPLORATION

Build the system of pulleys and masses without the central object so that the string looks horizontal. Make sure to use an appropriate length of string; if it is too short, the mass hangers from objects A and C will interfere with the pulleys when object B is lowered. Attach a central object and observe how the string sags. Decide on the origin from which you will measure the vertical position of object B.

Try changing the mass of objects A and C (keep them equal for the measurements, but you will want to explore the case where they are not equal). Are you able to create a stable system with unequal masses for A and C? Choose a set of masses for A and C that will allow you to get enough data to determine the vertical displacement as it depends on the mass of object B.

For the entire range of weights you will use, determine if the pulleys turn freely. How can you determine if the assumption that these pulleys are frictionless is good?

With the system in equilibrium, move the pulleys closer to one another and observe what happens to the vertical displacement of object B. Does the result make sense? Observe what happens when you move the pulleys farther apart. Decide on a separation distance between the two pulleys for your measurements.

Determine the range of masses for object B so that your system can be in equilibrium. Decide on the number of measurements that you will need to determine if your prediction agrees with the results. You may need to refer to your prediction to determine the proper range of masses.

**MEASUREMENT**

Using your plan from the exploration section, measure the vertical position of the central object as you increase its mass. Make a table and record your measurements. Also record the masses of objects A and C, and the horizontal separation of the pulleys. What units should you use? Don't forget to record your uncertainties.

**ANALYSIS**

Make a graph of the *measured* vertical displacement of the central object as a function of its mass based on your data. On the same graph, plot your *predicted* equation for vertical displacement versus mass of the central object.

Where do the two curves match? Where do the two curves start to diverge from one another? What does this tell you about the system?

**CONCLUSION**

What will you report to your supervisor? How does the vertical displacement of this object depend on its mass? Did your measurements of the vertical displacement of object B agree with your initial predictions? If not, why? What are the limits on the accuracy of your measurements and analysis?

What information would you need to apply your calculation to the walkway through the rain forest?

Estimate reasonable values for the information you need, and solve the problem for the walkway over the rain forest.

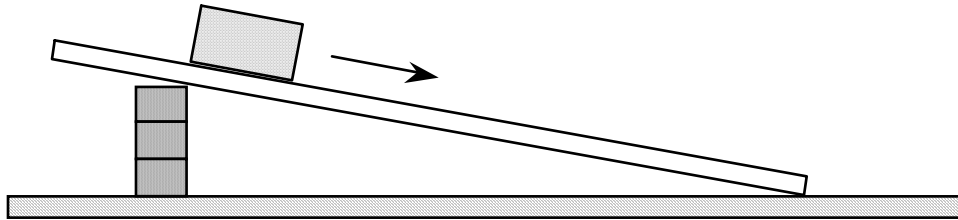


### PROBLEM #3: NORMAL FORCE AND THE KINETIC FRICTIONAL FORCE (PART A)

You have taken a job with a theater company and you are in charge of setting up the props. The props are transported in crates by a truck. The crates are unloaded by pushing them down a ramp. You realize that the frictional force is making your job difficult, so you decide to investigate how to reduce the frictional force. At your disposal are a small ramp and a wooden block. You are interested in determining how the kinetic frictional force depends on the normal force acting on an object. *As a first step, you decide to vary the normal force by changing the angle of the ramp.*

#### EQUIPMENT

A wooden block slides down a ramp, as shown below.



For this lab you will have wooden blocks, an aluminum track, a meter stick, a stopwatch, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).

#### PREDICTIONS

Sketch a graph of the magnitude of the kinetic frictional force on the sliding block as a function of the magnitude of the normal force.

Does the kinetic frictional force on the block **increase**, **decrease**, or **stay the same** as the normal force on the block increases? Is the relationship linear, or curved? Explain your reasoning.

#### WARM-UP

Read: Serway & Vuille Chapter 4, Sections 4.1 to 4.6

1. Make a sketch of the wood block sliding down the inclined track. Draw and label vectors to indicate the direction of the velocity and the direction of the acceleration. Also assign a symbol to the mass of the block and label it on the drawing.
2. Draw a free-body diagram of the forces on the block as it slides down the ramp. Draw the acceleration vector for the block near the free-body diagram. Choose a coordinate

- system, and draw the force vectors on your coordinate system (a force diagram). Remember that on a force diagram, the origin (tail) of all vectors is at the origin of the coordinate system. What angles between your force vectors and your coordinate axes are the same as the angle between the ramp and the table? Determine all of the angles between the force vectors and the coordinate axes.
- Write down Newton's 2nd law in both the  $x$  and  $y$  directions. For any forces that are at an angle to your coordinate system, be sure to consider the *components* along the  $x$  and  $y$  axes. It is also important to make sure that all of your signs are correct. For example, is the acceleration of the block positive or negative? Your answer will depend on how you define your coordinate system.
  - Using the equations in step 3, determine an equation for the *normal force* in terms of quantities you know or can measure (the mass of the block, the angle of the track, and  $g$ ).
  - Using the equations in step 3, determine an equation for the magnitude of the *kinetic frictional force* on the block in terms of quantities you know or can measure (the mass of the block, the angle of the track,  $g$ , and the acceleration of the block). How will you obtain the value of the acceleration from the video analysis software?
  - In this problem, you will change the normal force on the block by changing the angle of the track (keeping the mass of the block constant). If you increase the angle of the track, does the normal force on the block increase or decrease? Use your equation for the normal force from question 4 to explain your reasoning. What happens to the kinetic frictional force?
  - The normal force and the kinetic frictional force can also be related using a coefficient of kinetic friction,  $\mu_k$ . What is this relationship? Use the equation to sketch a graph of the magnitude of the kinetic frictional force on the block as a function of the magnitude of the normal force. How could you determine the value of  $\mu_k$  from this graph?
  - Use the simulation "Lab1Sim" (See Appendix F for a brief explanation of how to use the simulations) to simulate the effects of a wide range of friction coefficients, block masses, initial speeds, and track angles.

<b>EXPLORATION</b>
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Find an angle where the block accelerates smoothly down the ramp. Try this when the block has different masses on top of it. If the block sticks, try using more mass or tilting your ramp from table to floor instead of just using the wooden blocks. Find a mass that allows the block to accelerate smoothly down the track for a range of angles. What measurements could you make with a meter stick to determine the angle of incline?

Decide on a position where you will release the block that fits in the frame of the camera, and will give you enough data points for the motion. Practice releasing the block from this position with your chosen mass for the block. Determine how much time it takes for the block to slide down the track and estimate the number of video points you will get in that time. Are there enough points to make the measurement? Adjust the camera position, mass of the block, or the release position to give you enough data points. What will you use for a calibration object in your video?

Select a series of angles and a block mass that will make your measurements most reliable.

Write down your measurement plan.

### MEASUREMENT

Follow your measurement plan from the Exploration section to select a block mass and series of angles that will make your measurements the most reliable. When placing the camera, consider which part of the motion you wish to capture. Try different camera positions until you get the best possible video. *Hint: Your video may be easier to analyze if the motion on the video screen is purely horizontal. Why? It could be useful to rotate the camera!*

Take a video of the block's motion for one angle. *Make sure you measure and record the angle of the track with uncertainty.* Analyze your data as you go along (before making the next video) so you can determine how many videos you need to make, and what the angle should be for each video.

Repeat this procedure with the same mass but for different angles. Make sure each new angle allows the block to move freely down the incline. Be sure to measure and record your angles with the uncertainty. Collect enough data to convince yourself and others of your conclusion about how the kinetic frictional force on the block depends on the normal force on the block.

### ANALYSIS

Using VideoTOOL, determine the fit functions that best represent the *position vs. time graphs* in the x and y directions. How can you estimate the values of the constants of the function from the graph? You can waste a lot of time if you just try to guess the constants. What kinematic quantities do these constants represent?

Do the same for the *velocity vs. time graphs* in the x and y directions. Compare these functions with the position vs. time functions.

Determine the acceleration as the block slides down the track for a given angle. From your answers to the Warm-up questions, calculate the magnitude of the kinetic frictional force and the normal force on the block.

Graph the magnitude of the kinetic frictional force versus the magnitude of the normal force for one block mass and the different angles you used. On the same graph, show your predicted relationship. What physical quantity does the slope of the line represent?

What are the limitations on the accuracy of your measurements and analysis? Over what range of values does the measured graph best match the predicted graph? Do the two curves ever start to diverge from one another? What does this tell you about the system and the limitations on its accuracy?

**CONCLUSION**

How does the magnitude of the kinetic frictional force on an object depend on the normal force on the object? Did your measurements agree with your initial prediction? If they did not, explain why.

From your graph, determine the value of the coefficient of kinetic friction. Compare your value (with uncertainty) with values obtained by the other teams. Are they consistent? How does your value compare to the values in the table on page 16?

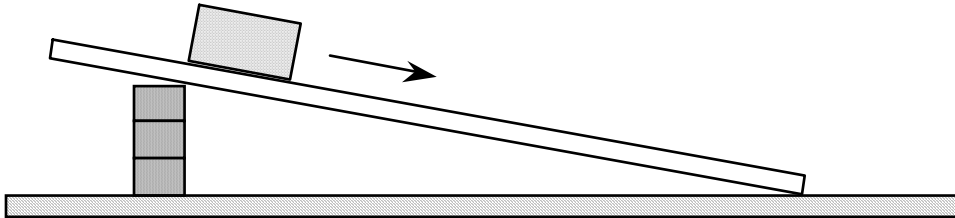
What role does the kinetic frictional force play as the crates go sliding down the ramp? How could you change the angle of the ramp to your advantage as you unload the props?

## PROBLEM #4: NORMAL FORCE AND THE KINETIC FRICTIONAL FORCE (PART B)

You have taken a job with a theater company and you are in charge of setting up the props. The props are transported in crates by a truck. They are unloaded by pushing them down a ramp. You realize that the frictional force is making your job difficult, so you decide to investigate how to reduce the frictional force. At your disposal are a small ramp and a felt block. You are interested in determining how the kinetic frictional force depends on the normal force acting on an object. As a first step (Part A), you varied the normal force by changing the angle of the ramp. As a second step, you decide to vary the normal force by changing the mass of the object.

### EQUIPMENT

A wooden block slides down a ramp, as shown below.



The tilt (angle) of the ramp with respect to the horizontal can be adjusted, and you can change the mass of the block by attaching weights to it. For this lab you will also have a meter stick, a video camera, and a computer with video analysis applications written in LabVIEW™ (VideoRECORDER and VideoTOOL).

### PREDICTION

Sketch a graph of the magnitude of the kinetic frictional force on the sliding block as a function of the magnitude of the normal force.

Do you expect the kinetic frictional force on the disk to **increase**, **decrease**, or **stay the same** as the normal force on the block increases? Explain your reasoning.

### WARM-UP

Read: Serway & Vuille Chapter 4, Sections 4.1 to 4.6

*Note: If you have completed Problem #3, refer to your previous answers to the Warm-up for questions 1-5 and question 7.*

1. Make a sketch of the wood block sliding down the inclined track. Draw and label vectors to indicate the direction of the velocity and the direction of the acceleration. Also assign a symbol to the mass of the block and label it on the drawing.
2. Draw a free-body diagram of the forces on the block as it slides down the ramp. Draw the acceleration vector for the block near the free-body diagram. Choose a coordinate system, and draw the force vectors on your coordinate system (a force diagram). Remember that on a force diagram, the origin (tail) of all vectors is at the origin of the coordinate system. What angles between your force vectors and your coordinate axes are the same as the angle between the ramp and the table? Determine all of the angles between the force vectors and the coordinate axes.
3. Write down Newton's 2nd law in both the  $x$  and  $y$  directions. For any forces that are at an angle to your coordinate system, be sure to consider the *components* along the  $x$  and  $y$  axes. It is also important to make sure that all of your signs are correct. For example, is the acceleration of the block positive or negative? Your answer will depend on how you define your coordinate system.
4. Using the equations in step 3, determine an equation for the *normal force* in terms of quantities you know or can measure (the mass of the block, the angle of the track, and  $g$ ).
5. Using the equations in step 3, determine an equation for the magnitude of the *kinetic frictional force* on the block in terms of quantities you know or can measure (the mass of the block, the angle of the track,  $g$ , and the acceleration of the block). How will you obtain the value of the acceleration from the video analysis software?
6. In this problem, you will change the normal force on the block by changing the mass of the block (keeping the angle of the track constant). If you increase the mass of the block, does the normal force on the block increase or decrease? Use your equation for the normal force from question 4 to explain your reasoning. What happens to the kinetic frictional force?
7. The normal force and the kinetic frictional force can also be related using a coefficient of kinetic friction,  $\mu_k$ . What is this relationship? Use the equation to sketch a graph of the magnitude of the kinetic frictional force on the block as a function of the magnitude of the normal force. How could you determine the value of  $\mu_k$  from this graph?
8. Use the simulation "Lab1Sim" (See Appendix F for a brief explanation of how to use the simulations) to simulate the effects of a wide range of friction coefficients, block masses, initial speeds, and track angles.

### EXPLORATION

Find an angle where the block accelerates smoothly down the ramp. Try this when the block has different masses on top of it. If the block sticks, try using more mass or tilting your ramp from table to floor instead of just using the wooden blocks. Find an angle that allows the block to accelerate smoothly down the track for a range of masses. What measurements could you make with a meter stick to determine the angle of incline?

Decide on a position where you will release the block that fits in the frame of the camera, and will give you enough data points for the motion. Practice releasing the block from this position with your

chosen angle for the track. Determine how much time it takes for the block to slide down the track and estimate the number of video points you will get in that time. Are there enough points to make the measurement? Adjust the camera position, angle of the track, or the release position to give you enough data points. What will you use for a calibration object in your video?

Select a series of block masses and a track angle that will make your measurements most reliable.

Write down your measurement plan.

### MEASUREMENT

Follow your measurement plan from the Exploration section to select a track angle and series of block masses that will make your measurements the most reliable. When placing the camera, consider which part of the motion you wish to capture. Try different camera positions until you get the best possible video. *Hint: Your video may be easier to analyze if the motion on the video screen is purely horizontal. Why? It could be useful to rotate the camera!*

Take a video of the block's motion for one block mass. *Make sure you measure and record the angle of the track and the block mass with uncertainty.* Analyze your data as you go along (before making the next video) so you can determine how many videos you need to make, and what the block mass should be for each video.

Repeat this procedure with the same mass but for different angles. Make sure each new angle allows the block to move freely down the incline. Be sure to measure and record your angles with the uncertainty. Collect enough data to convince yourself and others of your conclusion about how the kinetic frictional force on the block depends on the normal force on the block.

### ANALYSIS

Using VideoTOOL, determine the fit functions that best represent the *position vs. time graphs* in the x and y directions. How can you estimate the values of the constants of the function from the graph? You can waste a lot of time if you just try to guess the constants. What kinematic quantities do these constants represent?

Do the same for the *velocity vs. time graphs* in the x and y directions. Compare these functions with the position vs. time functions.

Determine the acceleration as the block slides down the track for a given angle. From your answers to the Warm-up questions, calculate the magnitude of the kinetic frictional force and the normal force on the block.

Graph the magnitude of the kinetic frictional force versus the magnitude of the normal force for one track angle and the different block masses you used. On the same graph, show your predicted relationship. What physical quantity does the slope of the line represent?

What are the limitations on the accuracy of your measurements and analysis? Over what range of values does the measured graph best match the predicted graph? Do the two curves ever start to

diverge from one another? What does this tell you about the system and the limitations on its accuracy?

<b>CONCLUSION</b>
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Explain how the magnitude of the kinetic frictional force on an object depends on the normal force on the object. Did your measurements agree with your initial prediction? If not, explain why. From your graph, determine the value of the coefficient of kinetic friction. Compare your value (with uncertainty) with values obtained by the other teams. Are they consistent? How does your value compare to the values in the table on page 16?

What role does the kinetic frictional force play as the crates go sliding down the ramp? How could you change the angle of the ramp to your advantage as you unload the props?

If you also did Problem #3, compare the results from Part A and Part B. Do you think it is better to vary the normal force by changing the angle or by changing the mass of the object? Why?



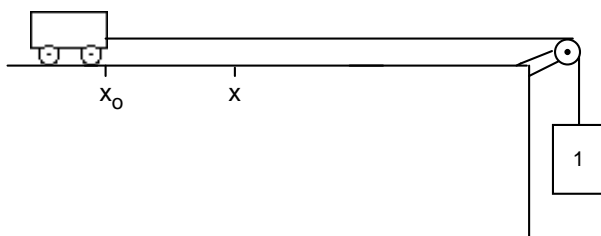
**Table of Coefficients of Friction\***

<b>Surfaces</b>	$\mu_s$	$\mu_k$
steel on steel	0.74	0.57
Aluminum on steel	0.61	0.47
copper on steel	0.53	0.36
steel on lead	0.9	0.9
copper on cast iron	1.1	0.3
copper on glass	0.7	0.5
wood on wood	0.25 - 0.5	0.2
glass on glass	0.94	0.4
metal on metal (lubricated)	0.15	0.07
Teflon on Teflon	0.04	0.04
rubber on concrete	1.0	0.8
ice on ice	0.1	0.03

\* All values are approximate.

## ✓ CHECK YOUR UNDERSTANDING

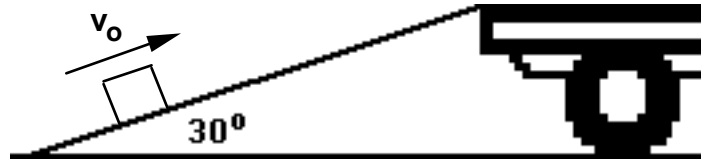
1. A cart and Block 1 are connected by a massless string that passes over a frictionless pulley, as shown in the diagram below.



When Block 1 is released, the string pulls the cart toward the right along a horizontal table. For each question below, explain the reason for your choice.

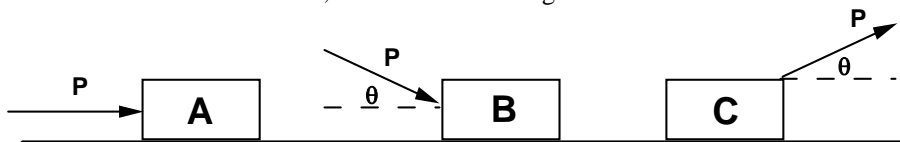
- a. The *speed* of the cart is:
- (a) constant.
  - (b) continuously increasing.
  - (c) continuously decreasing.
  - (d) increasing for a while, and constant thereafter.
  - (e) constant for a while, and decreasing thereafter.
- b. The *force* of the string on Block 1 is
- (a) zero.
  - (b) greater than zero but less than the weight of Block 1.
  - (c) equal to the weight of Block 1.
  - (d) greater than the weight of Block 1.
  - (e) It is impossible to tell without knowing the mass of Block 1.
- c. When the cart traveling on the table reaches position  $x$ , the string breaks. The cart then
- (a) moves on at a constant speed.
  - (b) speeds up.
  - (c) slows down.
  - (d) speeds up, then slows down.
  - (e) stops at  $x$ .
- d. Block 1 is now replaced by a larger block (Block 2) that exerts *twice the pull* as was exerted previously. The cart is again reset at starting position  $x_0$  and released. The string again breaks at position  $x$ . Now, what is the *speed* of the cart at position  $x$  *compared to* its speed at that point when pulled by the smaller Block 1?
- (a) Half the speed it reached before.
  - (b) Smaller than the speed it reached before, but not half of it.
  - (c) Equal to the speed it reached before.
  - (d) Double the speed it reached before.
  - (e) Greater than the speed it reached before, but not twice as great.

2. A crate is given an initial push up the ramp of a truck. It starts sliding up the ramp with an initial velocity  $v_0$ , as shown in the diagram below. The coefficient of kinetic friction between the box and the ramp is  $\mu_k$ .



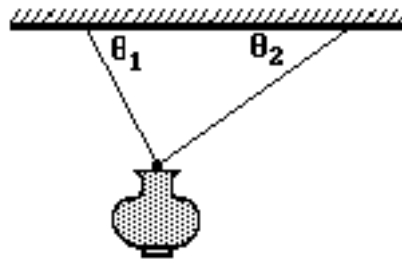
Will the magnitude of the acceleration of the sliding crate be greater on the way up or on the way back down the ramp? Or will the accelerations be the same? Explain using appropriate free-body diagrams.

3. The same constant force ( $P$ ) is applied to three identical boxes that are sliding across the floor. The forces are in different directions, as shown in the diagram below.



On which of the three boxes is the frictional force the largest? The smallest? Or is the frictional force on each box the same? Explain using appropriate free-body diagrams and Newton's second law.

4. A lamp is hanging from two light cords. The cords make unequal angles with the ceiling, as shown in the diagram at right.



- Draw the free-body diagram of the lamp. Clearly describe each force drawn.
- Is the horizontal component of the pull of the left cord on the lamp greater than, less than, or equal to the horizontal component of the pull of the right cord on the lamp? Explain your reasoning.
- Is the vertical component of the pull of the left cord on the lamp greater than, less than, or equal to the vertical component of the pull of the right cord on the lamp? Explain your reasoning.
- Is the vertical component of the pull of the left cord on the lamp greater than, less than, or equal to half the weight of the lamp? Explain your reasoning.

CHECK YOUR UNDERSTANDING

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TA Name: \_\_\_\_\_

## PHYSICS 1101 LABORATORY REPORT

### Laboratory III

Name and ID#: \_\_\_\_\_

Date performed: \_\_\_\_\_ Day/Time section meets: \_\_\_\_\_

Lab Partners' Names: \_\_\_\_\_

\_\_\_\_\_

Problem # and Title: \_\_\_\_\_

Lab Instructor's Initials: \_\_\_\_\_

Grading Checklist	Points
<b>LABORATORY JOURNAL:</b>	
<b>PREDICTIONS</b> (individual predictions and warm-up completed in journal before each lab session)	
<b>LAB PROCEDURE</b> (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
<b>PROBLEM REPORT:*</b>	
<b>ORGANIZATION</b> (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
<b>DATA AND DATA TABLES</b> (clear and readable; units and assigned uncertainties clearly stated)	
<b>RESULTS</b> (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
<b>CONCLUSIONS</b> (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
<b>TOTAL</b> (incorrect or missing statement of physics will result in a maximum of 60% of the total points achieved; incorrect grammar or spelling will result in a maximum of 70% of the total points achieved)	
<b>BONUS POINTS FOR TEAMWORK</b> (as specified by course policy)	

\* An "R" in the points column means to rewrite that section only and return it to your lab instructor within two days of the return of the report to you.

