

LABORATORY III

FORCES

The problems in this laboratory will help you further investigate objects' motions. Specifically, you will investigate the effects of the forces associated with different interactions between objects. In the first problem, you will investigate the effect of forces on a sliding object. To solve the second problem you will apply the force concept and the vector nature of forces to a situation in which nothing moves. The last three problems lead you to investigate some effects of 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 friction force.
- Improve your problem solving skills.

PREPARATION:

Read Paul M. Fishbane: Chapter 4 and Chapter 5. Review the motion of a cart moving down a ramp.

Before coming to lab you should be able to:

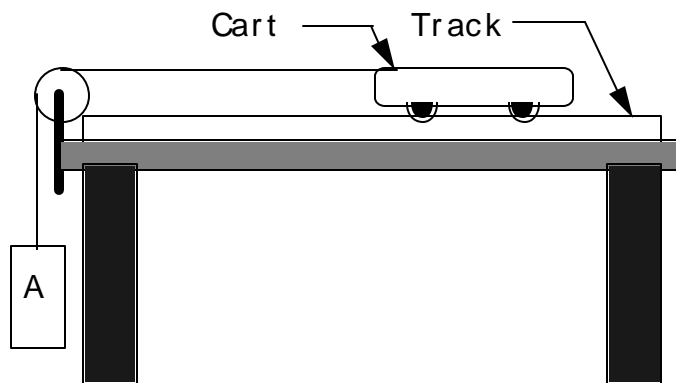
- Define and use sine, cosine and tangent for a right triangle.
- Describe the difference between mass and weight.
- Determine the net force on an object from its acceleration.
- Draw and use force diagrams.
- Resolve force into components vectors. Determine a force's magnitude and direction from its components.
- Explain what it means to say a system is in "equilibrium."
- Write the force law for a frictional force.

**PROBLEM #1:
FORCE AND MOTION**

You are a volunteer in the city's children's summer program. In one activity the children build and race model cars along a level surface. To give each car a fair start, another volunteer builds a special launcher with a string attached to the car at one end. The string passes over a pulley and from its other end hangs a block. The car starts from rest when the block is allowed to fall. After the block hits the ground, the string no longer exerts a force on the car and it continues along the track. You decide to calculate how the launch velocity of the car depends on the mass of the car, the mass of the block, and the distance the block falls. You hope to use the calculation to impress other volunteers by predicting the winner of each race.

EQUIPMENT

Released from rest, a cart is pulled along a level track by a hanging object as shown below:



You can vary the mass of Object A and the Cart. They are connected by a light string. Object A falls from a height shorter than the track's length. You will have a meter stick, a stopwatch, a mass hanger, a mass set, cart masses, a pulley, a pulley clamp, a piece of string and the video analysis equipment.

PREDICTION

Calculate the cart's velocity after object A has hit the floor. Express it as an equation, in terms of quantities mentioned in the problem, and draw graphs to show how the velocity changes with each variable.

WARM UP

Read: Fishbane Chapter 4. Read carefully Sections 4-5 and 4-6 and Examples 4-9 and 4-12.

To figure out your prediction, it is useful to have an organized problem-solving strategy such as the one outlined in the following questions. You might also find the Problem Solving techniques in the Competent Problem Solver useful.

1. Make three sketches of the problem situation, one for each of three instants: when the cart starts from rest, just before object A hits the floor, and just after object A hits the floor. Draw vectors to show the directions and relative magnitudes of the two objects' velocities and accelerations at each instant. Draw vectors to show all of the forces on object A and the cart at each instant. Assign appropriate symbols to all of the quantities describing the motion and the forces. If two quantities have the same magnitude, use the same symbol but write down your justification for doing so. (For example, the cart and object A have the same magnitude of velocity when the cart is pulled by the string. Explain why.) Decide on your coordinate system and draw it.
2. The "known" quantities in this problem are the mass of object A, the mass of the cart, and the height above the floor where object A is released. Assign a symbol to each known quantity. Identify all the unknown quantities. What is the relationship between what you really want to know (the velocity of the cart after object A hits the floor) and what you can calculate (the velocity of the cart just before object A hits the floor)?
3. Identify and write the physics principles you will use to solve the problem. (Hint: forces determine the objects' accelerations, so Newton's 2nd Law may be useful. You need to relate the magnitudes of forces on different objects to one another, so Newton's 3rd Law is probably also useful. Will you need any kinematics principles?) Write down any assumptions you have made which are necessary to solve the problem and justified by the physical situation. (For example, why will it be reasonable to ignore frictional forces in this situation?)
4. Draw one free-body diagram for object A, and a separate one for the cart after they start accelerating. Check to see if any of these forces are related by Newton's 3rd Law (Third Law Pairs). Draw the acceleration vector for the object next to its free-body diagram. Next, draw two separate coordinate systems; place vectors to represent each force acting on the cart on one coordinate system, and those acting on Object A on the second one (force diagrams). (The origin (tail) of each vector should be the origin of the coordinate system.) For each force diagram, write down Newton's 2nd law along each axis of the coordinate system. Make sure all of your signs are correct in the Newton's 2nd law equations. (For example, if the acceleration of the cart is in the + direction, is the acceleration of object A + or -? Your answer will depend on how you define your coordinate system.)
5. You are interested in the final velocity of the cart, but Newton's 2nd Law only gives you its acceleration; write down any kinematics equations which are appropriate to this situation. Is the acceleration of each object constant, or does it vary while object A falls?
6. Write down an equation, from those you have collected in steps 4 and 5 above, which relates what you want to know (the velocity of the cart just before object A hits the ground) to a quantity you either know or can find out (the acceleration of the cart and the time from the start until just before object A hits the floor). Now you have two new unknowns (acceleration and time). Choose one of these unknowns (for example, time) and write down a new equation (again from those collected in steps 4 and 5) which relates it to another quantity you either know or can find out (distance object A falls). If you have generated no additional unknowns, go back to determine the other original unknown (acceleration). Write down a new equation that relates the acceleration of the cart to other quantities you

either know or can find (forces on the cart). Continue this process until you generate no new unknowns. At that time you should have as many equations as unknowns.

7. Solve your mathematics to give the prediction.

Make a graph of the cart's velocity after object A has hit the floor as a function of the mass of object A, keeping constant the cart mass and the height through which object A falls.

Make a graph of the cart's velocity after object A has hit the floor as a function of the mass of the cart, keeping constant the mass of object A and the height through which object A falls.

Make a graph of the cart's velocity after object A has hit the floor as a function of the distance object A falls, keeping constant the cart mass and the mass of object A.

8. Does the shape of each graph make sense to you? Explain your reasoning.
9. Use the simulation "Lab4Sim" (See *Appendix F* for a brief explanation of how to use the simulations) to explore the effects of a very wide range of masses for the hanging object and the cart. If you believe friction may have affected your results, explore its effects with the simulation. Explore the effects of changing the mass of the string and the pulley. Do multiple runs and check the graphs produced. Use the simulation to compare the results with and without error. Look for the effects in the position vs. time graph or in the velocity vs. time graph.

EXPLORATION

Adjust the length of the string such that object A hits the floor well before the cart runs out of track. You will be analyzing a video of the cart *after* object A has hit the floor. Adjust the string length to give you a video that is long enough to allow you to analyze several frames of motion.

Choose a mass for the cart and find a useful range of masses for object A that allows the cart to achieve a reliably measurable velocity before object A hits the floor. Practice catching the cart before it hits the end stop on the track. Make sure that the assumptions for your prediction are good for the situation in which you are making the measurement. Use your prediction to determine if your choice of masses will allow you to measure the effect that you are looking for. If not, choose different masses.

Choose a mass for object A and find a useful range of masses for the cart.

Now choose a mass for object A and one for the cart and find a useful range of falling distances for object A.

Write down your measurement plan. (Hint: What do you need to measure with video analysis? Do you need video of the cart? Do you need video of object A?)

MEASUREMENT

Carry out the measurement plan you determined in the Exploration section.

Complete the entire analysis of one case before making videos and measurements of the next case. *A different person should operate the computer for each case.*

Make sure you measure and record the masses of the cart and object A (with uncertainties). Record the height through which object A falls and the time it takes to fall (measured with the stopwatch).

ANALYSIS

Ensure a **different** person in your group operates the computer for each case you are analyzing.

Determine the cart's velocity just after object A hits the floor from your video.

From the time and distance object A fell in each trial, calculate the cart's velocity just after object A hits the floor (assuming constant acceleration). Compare this value to the velocity you measured from the video. Are they consistent with each other?

What are the limitations on the accuracy of your measurements and analysis?

CONCLUSION

How does the velocity from your prediction equation compare with the two *measured* velocities (measured with video analysis, and also with stopwatch / meter stick measurements) compare in each case? Did your measurements agree with your initial prediction? If not, why?

Does the launch velocity of the car depend on its mass? The mass of the block? The distance the block falls?

If the same mass block falls through the same distance, but you change the mass of the cart, does the force the string exerts on the cart change? Is the force of the string on object A *always* equal to the weight of object A? Is it *ever* equal to the weight of object A? Explain your reasoning.

**PROBLEM #2:
FORCES IN EQUILIBRIUM**

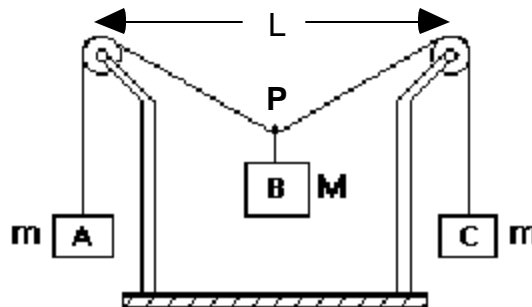
You have a summer job with a research group studying the ecology of a rain forest in South America. To avoid walking on the delicate rain forest floor, the team members walk along a rope walkway that the local inhabitants have strung from tree to tree through the forest canopy. Your supervisor is concerned 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. You need to determine how the sag of the walkway is related to the mass of a team member plus equipment when they are at the center of the walkway between two trees. 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 whole system is in equilibrium. 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 need to make some assumptions about what you can neglect. For this investigation, you will need a meter stick, two pulleys and two pulley clamps, three mass hangers and a mass set to vary the mass of object B.



PREDICTION

Write an equation for 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.

WARM UP

Read: Fishbane Chapter 4. Read carefully Section 4-6 and Example 4-12.

To solve this problem it is useful to have an organized problem-solving strategy such as the one outlined in the following questions. You should use a technique similar to that used in Problem 1 (where a more detailed set of Warm up questions is provided) to solve this problem.

1. Draw a sketch similar to the one in the Equipment section. Draw vectors that represent the forces on objects A, B, C, and point P. Use trigonometry to show how the vertical displacement of object B is related to the horizontal distance between the two pulleys and the angle that the string between the two pulleys sags below the horizontal.
2. The "known" (measurable) quantities in this problem are L, m and M; the unknown quantity is the vertical displacement of object B.
3. Write down the acceleration for each object. Draw separate force diagrams for objects A, B, C and for point P (if you need help, see your text). Use Newton's third law to identify pairs of forces with equal magnitude. What assumptions are you making?

Which angles between your force vectors and your horizontal coordinate axis are the same as the angle between the strings and the horizontal?

4. For each force diagram, write Newton's second law along each coordinate axis.
5. Solve your equations to predict how the vertical displacement of object B depends on its mass (M), the mass (m) of objects A and C, and the horizontal distance between the two pulleys (L). Use this resulting equation to make a graph of how the vertical displacement changes as a function of the mass of object B.
6. From your resulting equation, analyze what is the limit of mass (M) of object B corresponding to the fixed mass (m) of object A and C. What will happen if $M > 2m$?

EXPLORATION

Start with just the string suspended between the pulleys (no central object), so that the string looks horizontal. Attach a central object and observe how the string sags. Decide on the origin from which you will measure the vertical position of the object.

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).

Do the pulleys behave in a frictionless way for the entire range of weights you will use? How can you determine if the assumption of frictionless pulleys is a good one? Add mass to the central object to decide what increments of mass will give a good range of values for the measurement. Decide how measurements you will need to make.

MEASUREMENT

Measure the vertical position of the central object as you increase its mass. Make a table and record your measurements with uncertainties.

ANALYSIS

Graph the *measured* vertical displacement of the central object as a function of its mass. On the same graph, plot the *predicted* vertical displacement.

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

What are the limitations on the accuracy of your measurements and analysis?

CONCLUSION

What will you report to your supervisor? How does the vertical displacement of an object suspended on a string between two pulleys depend on the mass of that object? Did your measurements of the vertical displacement of object B agree with your predictions? If not, why? State your result in the most general terms supported by your analysis.

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

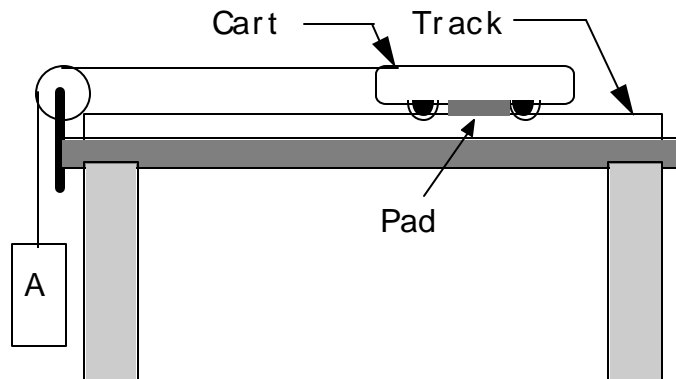
Estimate reasonable values for the information you need, and solve the problem for the walkway over the rain forest.

**PROBLEM #3:
FRICTIONAL FORCE**

You have joined a team trying to win the next solar powered car race and have been asked to investigate the effect of friction on the strategy of the race. In any race, sometimes the car coasts and sometimes it speeds up. One of your team has suggested that the frictional force is larger when a force causes an object to speed up than when it coasts and slows down “naturally” because of friction. Do you agree? You suggest making a laboratory model to measure the frictional force when it is speeding up and when it is coasting. You can’t measure force directly; to make the model useful you must calculate how *measurable* quantities will be affected by the friction force. Your model consists of a cart pulled along a level track by a light string. The string passes over a pulley and is tied to some weights hanging down. After the weights hit the ground, the cart continues to coast along the track. A pad between the cart and the track provides a variable friction force.

EQUIPMENT

A cart is pulled along a level track by a hanging object as shown below:



You can change the mass of Object A and the Cart. You will use the friction cart (with pad). You will have a meter stick, a mass hanger, a stopwatch, a mass set, a pulley clamp, cart masses, a string, and video analysis equipment.

PREDICTION

Express the frictional force on the cart in terms of quantities that you can measure in the experiment. Make an educated guess about the relationship between the frictional forces in the two situations.

WARM UP

Read: Fishbane Chapter 5. Read carefully Section 5-1 and Examples 5-3 and 5-6.

It is useful to have an organized problem-solving strategy such as the one outlined in the following questions. You should use a technique similar to that used in Problem 1 (where a more detailed set of Warm up questions are given) to solve this problem.

1. Make a drawing of the problem situation while the cart's speed is increasing, and another one while the cart's speed is decreasing. Draw vectors for each drawing to represent all quantities that describe the *motions* of the block and the cart and the *forces* acting on them. Assign appropriate symbols to each quantity. If two quantities have the same magnitude, use the same symbol. Choose a coordinate system and draw it.
2. List the "known" (controlled by you) and "unknown" (to be measured or calculated) quantities in this problem.
3. Write down what principles of Physics you will use to solve the problem. 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.
4. Start with the time interval in which the string exerts a force on the cart (before object A hits the floor). Draw separate free-body and force diagrams for object A and for the cart after they start accelerating. Check to see if any force pairs are related by Newton's 3rd Law. For each force diagram (one for the car and one for object A), write down Newton's 2nd law along each axis of the coordinate system. Be sure all signs are correct.
5. Write down an equation, from those you have collected in step 4 above, that relates what you want to know (the frictional force on the cart) to a quantity you either know or can find out (the acceleration of the cart). Is the force the string exerts on the cart equal to, greater than, or less than the gravitational pull on object A? Explain. Solve your equations for the frictional force on the cart in terms of the masses of the cart, the mass of object A, and the acceleration of the cart.
6. Now deal with the time interval in which the string does not exert a force on the cart (after object A hits the floor). Draw a free-body and force diagram for the cart. Write down Newton's 2nd law along each axis of the coordinate system. Be sure your signs are correct. Solve your equation for the frictional force on the cart in terms of the masses of the cart, the mass of object A, and the acceleration of the cart. You can now determine the frictional force on the cart for each case by measuring the acceleration of the cart.
7. Use the simulation "Lab4Sim" (See *Appendix F* for a brief explanation of how to use the simulations) to explore the effects of a very wide range of friction coefficients. If you believe friction may have affected your results, explore its effects with the simulation. Explore the effects of changing the mass of the string and the pulley. Do multiple runs and check the graphs produced. Use the simulation to compare the results with and without error. Look for the effects in the position vs. time graph or in the velocity vs. time graph.

EXPLORATION

Adjust the length of the string such that object A hits the floor well before the cart runs out of track. You will be analyzing a video of the cart both *before and after* object A has hit the floor. Consider how to distinguish these two cases in the same video. Adjust the string length to give you a video that is long enough to allow you to analyze enough of the motion to measure the cart's acceleration.

Choose a mass for the cart and find a mass for object A that allows you to reliably measure the cart's acceleration both *before* and *after* object A hits the floor. Because you are comparing the case of the string pulling on the cart with the case of the string not pulling on the cart, make sure the force of the string on the cart is as large as possible. Practice catching the cart before it hits the end stop on the track. Make sure the assumptions for your prediction are good for the situation in which you make the measurement. Use your prediction to determine if your choice of masses will allow you to measure the effect you are looking for. If not, choose different masses.

Write down your measurement plan. (Do you need video of the cart? Do you need video of object A?)

MEASUREMENT

Carry out the measurement plan you determined in the Exploration section.

Measure and record the mass of the cart and object A (with uncertainties). Record the height through which object A (the mass hanger) falls and the time it takes to fall.

Make enough measurements to convince yourself and others of your conclusion.

ANALYSIS

Using the height and time of object A's fall for each trial, calculate the cart's acceleration *before* object A hits the floor. Use the video to determine the cart's acceleration *before* and *after* object A. Is the "before" acceleration from the video consistent with the one you calculate based on time and height of fall?

Use the acceleration to determine the friction force before and after object A hits the floor.

What are the limitations on the accuracy of your measurements and analysis?

CONCLUSION

Was the frictional force the same whether or not the string exerted a force on it? Does this agree with your initial prediction? If not, why?

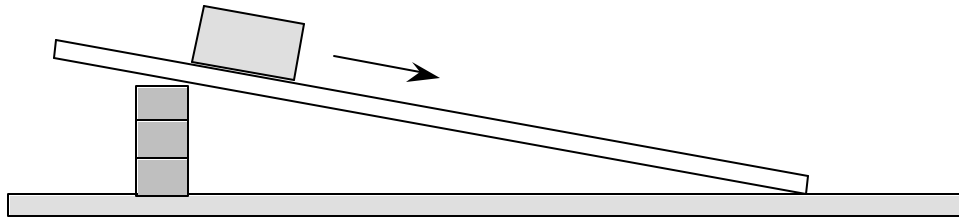
**PROBLEM #4:
NORMAL FORCE AND KINETIC FRICTIONAL FORCE I**

You work for a consulting firm with contracts to test the mechanical properties of different materials. A customer wants you to determine the coefficient of kinetic friction for wood on aluminum.

You decide to measure the coefficient of kinetic friction by graphing the frictional force as a function of the normal force when a wood block slides down an aluminum track. The coefficient of kinetic friction is the slope of that graph. Because there is measurement uncertainty no matter how you do the measurement, you decide to vary the normal force in two different ways. You divide your group into two teams. The other team will vary the normal force by changing the angle of incline of the track (Problem #5). *Your team will vary the normal force by changing the mass of the block.*

EQUIPMENT

A wooden block slides down an aluminum track, as shown below.



The tilt of the aluminum track with respect to the horizontal can be adjusted. You can change the mass of the wooden block by attaching additional mass to it. With video analysis equipment you can determine the acceleration of the wooden block sliding down the aluminum track. Two wooden blocks, a meter stick, a stopwatch and a mass set are available for this experiment.

PREDICTIONS

To make sense of your experimental results, you need to determine the relationship between the coefficient of kinetic friction and the quantities that you can measure in experiment. You can look up the accepted value of the coefficient of friction from the Table of Coefficients of Friction near the end of this laboratory. Explain your reasoning.

WARM UP

Read: Fishbane Chapter 5. Read carefully Sections 5-2 and Example 5-8.

To figure out your prediction you must determine how to calculate the normal force and the kinetic frictional force from quantities you can measure in this problem. It is useful to have an organized problem-solving strategy such as the one outlined in the following questions. You should use a technique similar to that used in Problem 1 (where a more detailed set of Warm up questions are given) to solve this problem.

1. What do you expect for the shape of a graph of kinetic friction force vs. normal force? What do you expect for the slope?
2. Make a drawing of the problem situation similar to the one in the Equipment section. Draw vectors to represent all quantities that describe the motion of the block and the forces on it. What measurements can you make with a meter stick to determine the angle of incline? Choose a coordinate system. What is the reason for using the coordinate system you picked?
3. What measurements can you make to enable you to calculate the kinetic frictional force on the block? What measurements can you make to enable you to calculate the normal force on the block? Do you expect the kinetic frictional force the track exerts on the wooden block to **increase, decrease, or stay the same** as the normal force on the wooden block increases? Explain your reasoning.
4. Draw a free-body diagram of the wooden block as it slides down the aluminum track. Draw the acceleration vector for the block near the free-body diagram. Transfer the force vectors to your coordinate system. What angles between your force vectors and your coordinate axes are the same as the angle between the aluminum track and the table? Determine all of the angles between the force vectors and the coordinate axes.
5. Write down Newton's 2nd Law for the sliding block along each coordinate axis.
6. Using the equations from step 5, determine an equation for the kinetic frictional force in terms of quantities you can measure. Next determine an equation for the normal force in terms of quantities you can measure. In your experiment, the measurable quantities include the mass of the block, the angle of incline and the acceleration of the cart.
7. 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 at which the wooden block accelerates smoothly down the aluminum track. Try this when the wooden block has different masses on top of it. Select an angle and series of masses that will make your measurements most reliable.

MEASUREMENT

Keeping the aluminum track at the same angle, take a video of the wooden block's motion. Keep the track fixed when block is sliding down. *Make sure you measure and record that angle. You will need it later.*

Repeat this procedure for different block masses to change the normal force. Make sure the block moves smoothly down the incline for each new mass. Make sure every time you use the same surface of the block to contact the track.

Collect enough data to convince yourself and others of your conclusion about how the kinetic frictional force on the wooden block depends on the normal force on the wooden block.

ANALYSIS

For each new block mass and video, calculate the magnitude of the kinetic frictional force from the acceleration. Also determine the normal force on the block.

Graph the magnitude of the kinetic frictional force against the magnitude of the normal force, for a constant angle of incline. Use the graph to find the coefficient of kinetic friction.

CONCLUSION

What is the coefficient of kinetic friction for wood on aluminum? How does this compare to the value on the table? Does the shape of the measured graph match the shape of the predicted graph? Over what range of values does the measured graph best match the predicted graph?

What are the limitations on the accuracy of your measurements and analysis?

If available, compare your value of the coefficient of kinetic friction (with uncertainty) with the value obtained by the different procedure given in the next problem. Are the values consistent? Which way of varying the normal force to measure the coefficient of friction do you think is better? Why?

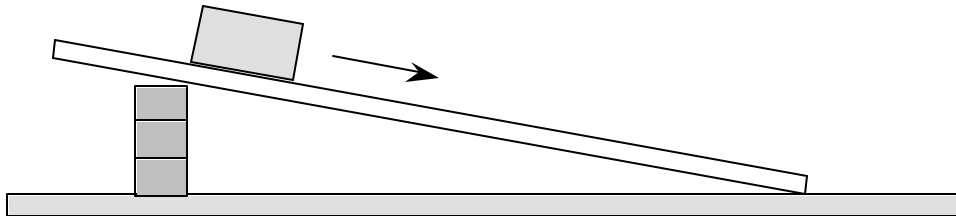
**PROBLEM #5:
NORMAL FORCE AND KINETIC FRICTIONAL FORCE II**

You work for a consulting firm with contracts to test the mechanical properties of different materials. A customer wants your group to determine the coefficient of kinetic friction for wood on aluminum.

You decide to measure the coefficient of kinetic friction by graphing the frictional force as a function of the normal force when a wood block slides down an aluminum track. The coefficient of kinetic friction is the slope of that graph. Because there is experimental measurement uncertainty no matter how you do the measurement, you decide to vary the normal force in two different ways. You divide your group into two teams. The other team will vary the normal force by changing the mass of the block (Problem #4). *Your team will vary the normal force by changing the angle of incline of the aluminum track.*

EQUIPMENT

A wooden block slides down an aluminum track, as shown below.



The tilt of the aluminum track with respect to the horizontal can be adjusted. You can change the mass of the wooden block by attaching additional mass to it. With video analysis equipment you can determine the acceleration of the wooden block sliding down the aluminum track. Two wooden blocks, a meter stick, a stopwatch and a mass set are available for this experiment.

PREDICTIONS

To make sense of your experimental results, you need to determine the relationship between the coefficient of kinetic friction and the quantities that you can measure in experiment. You can look up the accepted value of the coefficient of friction from the Table of Coefficients of Friction near the end of this laboratory. Explain your reasoning.

WARM UP

Read: Fishbane Chapter 5. Read carefully Sections 5-2 and Example 5-8.

To figure out your prediction you must determine how to calculate the normal force and the kinetic frictional force from the quantities you can measure in this problem. It is useful to have an organized problem-solving strategy such as the one outlined in the following questions. You should use a technique similar to that used in Problem 1 (where a more detailed set of Warm up questions are given) to solve this problem.

1. What do you expect for the shape of a graph of kinetic friction force vs. normal force? What do you expect for the slope?
2. Make a drawing of the problem situation similar to the one in the Equipment section. Draw vectors to represent all quantities that describe the motion of the block and the forces on it. What measurements can you make with a meter stick to determine the angle of incline? Choose a coordinate system. What is the reason for using the coordinate system you picked?
3. What measurements can you make to enable you to calculate the kinetic frictional force on the block? What measurements can you make to enable you to calculate the normal force on the block? Do you expect the normal force the track exerts on the wooden block to **increase**, **decrease**, or **stay the same** as the angle of the track increases? How do you expect the kinetic frictional force the track exerts on the wooden block to change if the normal force changes? Explain your reasoning.
4. Draw a free-body diagram of the wooden block as it slides down the aluminum track. Draw the acceleration vector for the block near the free-body diagram. Transfer the force vectors to your coordinate system. What angles between your force vectors and your coordinate axes are the same as the angle between the aluminum track and the table? Determine all of the angles between the force vectors and the coordinate axes.
5. Write down Newton's 2nd Law for the sliding block along each coordinate axis.
6. Using the equations from step 5, determine an equation for the kinetic frictional force in terms of quantities you can measure. Next determine an equation for the normal force in terms of quantities you can measure. In our experiment, the measurable quantities include the mass of the block, the angle of incline and the acceleration of the cart.
7. 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 a mass for which the wooden block accelerates smoothly down the aluminum track. Try this several different angles of the aluminum track.

Try different block masses. Select a mass that gives you the greatest range of track angles for reliable measurements.

MEASUREMENT

Keeping the wooden block's mass fixed, take a video of its motion. Keep the track fixed when block is sliding down. *Make sure you measure and record each angle.*

Repeat this procedure for different track angles. Make sure the block moves smoothly down the incline for each new angle. Make sure every time you use the same surface of the block to contact the track.

Collect enough data to convince yourself and others of your conclusion about how the kinetic frictional force on the wooden block depends on the normal force on the wooden block.

ANALYSIS

For each angle and video, calculate the magnitude of the kinetic frictional force from the acceleration. Also determine the normal force on the block.

Graph the magnitude of the kinetic frictional force against the magnitude of the normal force for a constant block mass. Use the graph to find the coefficient of kinetic friction.

CONCLUSION

What is the coefficient of kinetic friction for wood on aluminum? How does this compare to the value on the table? Does the shape of the measured graph match the shape of the predicted graph? Over what range of values does the measured graph best match the predicted graph?

What are the limitations on the accuracy of your measurements and analysis?

If available, compare your value of the coefficient of kinetic friction (with uncertainty) with the value obtained by the procedure of the preceding problem. Are the values consistent? Which way of varying the normal force to measure the coefficient of friction do you think is better? Why?

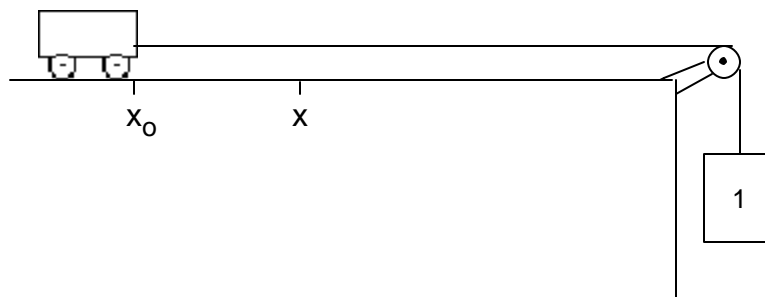
TABLE: COEFFICIENTS OF FRICTION*

Surfaces	μ_s	μ_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
Wood on Aluminum		0.25-0.3

* 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.

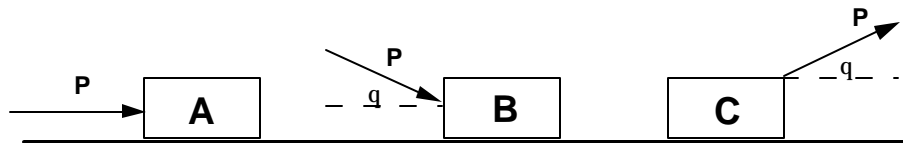
☑ CHECK YOUR UNDERSTANDING

2. A crate is given an initial push up the ramp of a large 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 floor is μ_k .



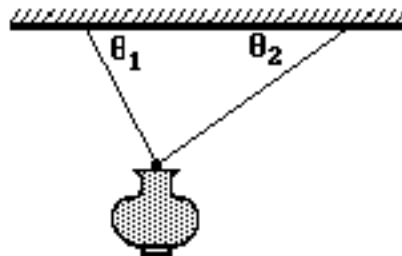
Will the magnitude of the acceleration of the sliding crate be greater on the way up or on the way back down the ramp? Or will the accelerations be the same? Explain using appropriate force diagrams.

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 force 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.



- a. Draw the force diagram of the lamp. Clearly describe each force drawn.
- b. 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.
- c. 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.
- d. 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.

TA Name: _____

PHYSICS 1301 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*
LABORATORY JOURNAL:	
PREDICTIONS (individual predictions and warm-up completed in journal before each lab session)	
LAB PROCEDURE (measurement plan recorded in journal, tables and graphs made in journal as data is collected, observations written in journal)	
PROBLEM REPORT:	
ORGANIZATION (clear and readable; logical progression from problem statement through conclusions; pictures provided where necessary; correct grammar and spelling; section headings provided; physics stated correctly)	
DATA AND DATA TABLES (clear and readable; units and assigned uncertainties clearly stated)	
RESULTS (results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)	
CONCLUSIONS (comparison to prediction & theory discussed with physics stated correctly ; possible sources of uncertainties identified; attention called to experimental problems)	
TOTAL (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)	
BONUS POINTS FOR TEAMWORK (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.

