LABORATORY IV
CONSERVATION OF ENERGY

In this lab you will begin to use the principle of *conservation of energy* to determine the motion resulting from interactions that are difficult to analyze using force concepts alone. You will explore how conservation of energy is applied to real interactions. Keep in mind that **energy is always conserved**, but it is sometimes difficult to calculate the value of all energy terms relevant for an interaction. Some energy may be transferred into or out of the system of interest, and some may be transformed to internal energy of the system. One outcome can be that some fraction of a system's energy of motion before an interaction is not visible energy of motion after the interaction. Since the energy is no longer observable in the macroscopic motion of objects, we sometimes say that the energy is "dissipated" in the interaction.

The first four problems in this laboratory explore the application of conservation of energy using carts. The fifth problem deals with the very real complication of friction.

OBJECTIVES:

Successfully completing this laboratory should enable you to:

- Use conservation of energy to predict the outcome of interactions between objects.
- Choose a useful system when using conservation of energy.
- Identify different types of energy when applying energy conservation to real systems.
- Decide when conservation of energy is not useful to predict the outcome of interactions between objects.

PREPARATION:

Read Paul M. Fishbane: Chapter 6, Chapter 7. You should also be able to:

- Analyze the motion of an object using video analysis.
- Calculate the kinetic energy of a moving object.
- Calculate the work transferred to or from a system by an external force.
- Calculate the total energy of a system of objects.
- Calculate the gravitational potential energy of an object with respect to the earth.

PROBLEM #1:
KINETIC ENERGY AND WORK I

You are working at a company that designs pinball machines and have been asked to devise a test to determine the efficiency of some new magnetic bumpers. You know that when a normal pinball rebounds off traditional bumpers, some of the initial energy of motion is "dissipated" in the deformation of the ball and bumper, thus slowing the ball down. The lead engineer on the project assigns you to determine if the new magnetic bumpers are more efficient. The engineer tells you that the efficiency of a collision is the ratio of the final kinetic energy to the initial kinetic energy of the system.

To limit the motion to one dimension, you decide to model the situation using a cart with a magnet colliding with a magnetic bumper. You will use a level track, and use a video data acquisition system to measure the cart's velocity before and after the collision. You begin to gather your camera and data acquisition system when your colleague suggests a method with simpler equipment. Your colleague claims it would be possible to release the cart from rest on an inclined track and make measurements with just a meter stick. You are not sure you believe it, so you decide to measure the energy efficiency both ways, and determine the extent to which you get consistent results. *For this problem, you will use the level track. For problem #2, you will work with the inclined track.*

EQUIPMENT

You will use the video analysis equipment to analyze the motion of a cart colliding with an end stop (the magnetic bumper) on the track. You will also have a meter stick, a stopwatch and a balance to measure the mass of the cart.

PREDICTIONS

Calculate the energy efficiency of the bumper discussed in the problem in terms of the least number of quantities that you can easily measure in the situation of a level track. Calculate the energy dissipated during the impact with the bumper in terms of those measurable quantities.

WARM UP

Read: Fishbane Chapter 6, section 6.1.

1. It is useful to have an organized problem-solving strategy. The following questions will help with your prediction and the analysis of your data.

2. Make a drawing of the cart on the level track before and after the impact with the bumper. Define your system. Label the velocity and kinetic energy of all objects in your system before and after the impact.

3. Write an expression for the efficiency of the bumper in terms of the final and initial kinetic energy of the cart.

4. Write an expression for the energy dissipated during the impact with the bumper in terms of the kinetic energy before the impact and the kinetic energy after the impact.

EXPLORATION

Review your exploration notes for measuring a velocity using video analysis. Practice pushing the cart with different velocities, slowly enough that the cart will never contact the bumper (end stop) during the impact when you make a measurement. Find a range of velocities for your measurement. Set up the camera and tripod to give you a useful video of the collision immediately before and after the cart collides with the bumper.

Although the effect of friction is small in our lab, you may want to estimate it. Make a schedule to test the effect of friction by the data from video.

MEASUREMENT

Take the measurements necessary to determine the kinetic energy before and after the impact with the bumper. What is the most efficient way to measure the velocities with the video equipment? Take data for several different initial velocities.

ANALYSIS

Calculate the efficiency of the bumper for the level track. Does your result depend on the velocity of the cart before it hits the bumper?

CONCLUSION

What is the efficiency of the magnetic bumpers? How much energy is dissipated in an impact? What is effect of friction in your experiment? State your results in the most general terms supported by your analysis.

If available, compare your value of the efficiency (with uncertainty) with the value obtained by the different procedure given in the next problem. Are the values consistent? Which way to measure the efficiency of the magnetic bumper do you think is better? Why?

PROBLEM #2:
KINETIC ENERGY AND WORK II

You are working at a company that designs pinball machines and have been asked to devise a test to determine the efficiency of some new magnetic bumpers. You know that when a normal pinball rebounds off traditional bumpers, some of the initial energy of motion is "dissipated" in the deformation of the ball and bumper, thus slowing the ball down. The lead engineer on the project assigns you to determine if the new magnetic bumpers are more efficient. The engineer tells you that the efficiency of a collision is the ratio of the final kinetic energy to the initial kinetic energy of the system.

To limit the motion to one dimension, you decide to model the situation using a cart with a magnet colliding with a magnetic bumper. You will use a level track, and use a video data acquisition system to measure the cart's velocity before and after the collision. You begin to gather your camera and data acquisition system when your colleague suggests a method with simpler equipment. Your colleague claims it would be possible to release the cart from rest on an inclined track and make measurements with just a meter stick. You are not sure you believe it, so you decide to measure the energy efficiency both ways, and determine the extent to which you get consistent results. *For this problem, you will use the inclined track. For problem #1, you will work with the level track.*

EQUIPMENT

You will have a meter stick, a stopwatch, cart masses and a wooden block to create the incline. You may also use the video analysis equipment to estimate the effect of friction.

PREDICTIONS

Calculate the energy efficiency of the bumper (with friction and without) in terms of the least number of quantities that you can easily measure in the situation of an inclined track.

WARM UP

Read: Fishbane Chapter 6, sections 6.1-6.2.

The following questions will help you to make your prediction and analyze your data.

1. Make a drawing of the cart on the ***inclined track*** at its initial position (before you release the cart) and just before the cart hits the bumper. Define the system. Label the kinetic energy of all objects in your system at these two points, the distance the cart traveled, the angle of incline, and the initial height of the cart above the bumper.

2. Now make another drawing of the cart on the inclined track just after the collision with the bumper *and* at its maximum rebound height. Label kinetic energy of the cart at these two

points, the distance the cart traveled, the angle of the ramp, and the rebound height of the cart above the bumper.

3. Write an expression for the efficiency of the bumper in terms of the kinetic energy of the cart just before the impact and the kinetic energy of the cart just after the impact.

4. Draw a force diagram of the cart as it moves down the track. Which force component does work on the cart (i.e., causes a transfer of energy into the cart system)? Write an expression for the work done on the cart. How is the angle of the ramp related to the distance the cart traveled and the initial height of the cart above the bumper? *How does the kinetic energy of the cart just before impact compare with the work done on the cart?*

5. Draw a force diagram of the cart as it moves up the track. Which force component does work on the cart (i.e., causes a transfer of energy out of the cart system)? Write an expression for the work done on the cart. *How does the kinetic energy of the cart just after impact compare with the work done on the cart?*

6. Write an expression for the efficiency of the bumper in terms of the cart's initial height above the bumper and the cart's maximum rebound height above the bumper.

7. Write an expression for the energy dissipated during the impact with the bumper in terms of the kinetic energy of the cart just before the impact and the kinetic energy of the cart after the impact. Re-write this expression in terms of the cart's initial height above the bumper and the cart's maximum rebound height above the bumper.

8. Repeat the procedure, considering the effect of friction.

EXPLORATION

Find a useful range of heights and inclined angles that will not cause damage to the carts or bumpers. Make sure that the cart will never contact bumper (end stop) during the impact. Decide how you are going to consistently measure the *height* of the cart.

You may want to estimate the effect of friction. Make a schedule to test the effect of friction by the video analysis equipment. How can you find the average frictional force when the cart moves on the inclined track? How much energy is dissipated by friction?

MEASUREMENT

Take the measurements necessary to determine the kinetic energy of the cart just before and after the impact with the bumper. Take data for several different initial heights.

ANALYSIS

Calculate the efficiency of the bumper for the inclined track. Does your result depend on the velocity of the cart before it hits the bumper?

CONCLUSION

What is the efficiency of the magnetic bumpers? How much energy is dissipated in an impact? State your results in the most general terms supported by your analysis. Is effect of friction significant?

If available, compare your value of the efficiency (with uncertainty) with the value obtained by the different procedure given in the preceding problem. Are the values consistent? Which way to measure the efficiency of the magnetic bumper do you think is better? Why?

PROBLEM #3:
ENERGY IN COLLISIONS
WHEN OBJECTS STICK TOGETHER

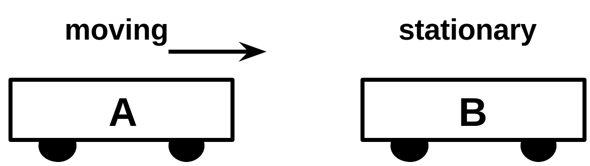
You work with the Minnesota Traffic Safety Board. You are helping to write a report about the damage done to vehicles in different kinds of traffic accidents. Your boss wants you to concentrate on the damage done when a moving vehicle hits a stationary vehicle and they stick together.

You know that in a traffic collision, some of the initial energy of motion is "dissipated" in the deforming (damaging) of the vehicles. Your boss believes that the amount of damage done in such a collision depends only on the total mass of the two vehicles and the initial kinetic energy of the moving vehicle, but other members of the team disagree. Is your boss correct?

You decide to test your prediction by measuring the energy efficiency of three different cart collisions: one in which the moving cart is more massive, one in which the stationary cart is more massive, and one in which the moving and stationary carts are equally massive.

EQUIPMENT

You will use the track and carts with which you are familiar. For this problem, cart A is given an initial velocity towards a stationary cart B. There are pads at the end of each cart. The pads allow the carts to stick together after the collision. Video analysis equipment allows you to determine the cart velocities before and after the collision. You also have a meter stick, a stopwatch, two end stops and cart masses.



PREDICTION

Consider the three cases described in the problem, with the same total mass of the carts for each case ($m_A + m_B$ = constant). Rank the collisions from most efficient to least efficient. (Make an educated guess and explain your reasoning.)

Calculate the energy dissipated in a collision in which the carts stick together, as a function of the mass of each cart, the initial kinetic energy of the system, and the energy efficiency of the collision. Assuming the kinetic energy of the incoming vehicle is the same in each case, use your calculation and your educated guess to determine which collision will cause the most damage.

WARM UP

Read: Fishbane Chapter 6, sections 6.1-6.2.

The following questions will help you with the calculation part of the prediction and with the analysis of your data.

1. Draw two pictures, one showing the situation before the collision and the other one after the collision. Is it reasonable to neglect friction? Draw velocity vectors on your sketch. Define your system. If the carts stick together, what must be true about their final velocities? Write down the energy of the system before and after the collision.

2. Write down the energy conservation equation for this collision (Remember to take into account the energy dissipated).

3. Write an equation for the efficiency of the collision in terms of the final and initial kinetic energy of the carts, and then in terms of the cart masses and their initial and final speeds.

4. Solve your equations for the energy dissipated.

5. Use the simulation "Lab3Sim" (See *Appendix F* for a brief explanation of how to use the simulations) to explore the conditions of this problem. For this problem you will want to set the elasticity to zero.

EXPLORATION

Practice rolling the cart so the carts will stick together after colliding. Carefully observe the carts to determine whether either cart leaves the grooves in the track. Minimize this effect so that your results are reliable.

Try giving the moving cart various initial velocities over the range that will give reliable results. Note qualitatively the outcomes. Choose initial velocities that will give you useful videos.

Try varying the masses of the carts so that the mass of the initially moving cart covers a range from greater than the mass of the stationary cart to less than the mass the stationary cart while keeping the total mass of the carts the same. Is the same range of initial velocities useful with different masses? If the moving cart should have approximately the same kinetic energy for each collision, how should its speed depend on its mass? What masses will you use in your final measurement?

MEASUREMENT

Record the masses of the two carts. Make a video of their collision. Examine your video and decide if you have enough frames to determine the velocities you need. Do you notice any peculiarities that might suggest the data is unreliable?

Analyze your data as you go along (before making the next video), so you can determine how many different videos you need to make, and what the carts' masses should be for each video. Collect enough data to convince yourself and others of your conclusion about how the energy efficiency of this type of collision depends on the relative masses of the carts.

Save all of your data and analysis. You will use it again for Laboratory V.

ANALYSIS

Determine the velocity of the carts before and after the collision using video analysis. For each video, calculate the kinetic energy of the carts before and after the collision.

Calculate the energy efficiency of each collision. Into what other forms of energy do you think the cart's initial kinetic energy is most likely to transform?

Graph how the energy efficiency varies with mass of the initially moving cart (keeping the total mass of both carts constant). What function describes this graph? Repeat for energy efficiency as a function of initial velocity.

Make sure everyone in your group gets the chance to operate the computer.

CONCLUSION

Which case ($m_A = m_B$, $m_A > m_B$, or $m_A < m_B$) is the energy efficiency the largest? The smallest? Does this make sense? (Imagine extreme cases, such as a flea running into a truck and a truck running into a flea. In which case must the incoming “vehicle” be moving faster to satisfy your boss’s assumption about initial kinetic energy? Which collision might cause more damage to the flea? To the truck?)

Was a significant portion of the energy dissipated? Into what other forms of energy do you think the cart's initial kinetic energy is most likely to transform?

Can you approximate the results of this type of collision by assuming that the energy dissipated is small?

Was your boss right? Is the same amount of damage done to the vehicles when a car hits a stationary truck and they stick together as when the truck hits the stationary car (given the same initial kinetic energies)? State your results that support this conclusion.

Suppose two equal mass cars traveling with equal speeds in opposite directions collide head on and stick together. What fraction of the energy is dissipated? Try it.

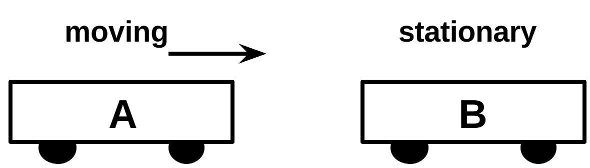
PROBLEM #4:
ENERGY IN COLLISIONS
WHEN OBJECTS BOUNCE APART

You work for a cable TV sports network, which is interested in developing a new form of "extreme bowling". One feature of the game will be that the masses of the (rolling) bowling balls and (stationary) bowling pins will vary greatly over the course of a match. Another feature is that they will bounce off each other when a ball runs into a pin. Your boss speculates that the energy efficiency of the collisions is useful information, and that it will change with the speed of the ball and the relative masses of the balls and pins. In order to save the most spectacular collisions until the final frames, your boss asks you to determine the energy efficiencies and energy dissipation over a range of ball masses and pin masses. Is your boss correct?

You decide to test your prediction with three different cart collisions: one in which the moving cart is more massive, one in which the stationary cart is more massive, and one in which the moving and stationary carts are equally massive. As a control, you assume that the total mass of the colliding objects remains constant. For your model you use the most efficient bumper you can think of, a magnetic bumper.

EQUIPMENT

You will use the same equipment as in Problem 3. Magnets at the end of each cart are used as bumpers to ensure that the carts bounce apart after the collision. The video analysis equipment is available to determine the velocities of the carts. You will also have a meter stick, a stopwatch, two end stops and cart masses.



PREDICTION

Consider the three cases described in the problem, with the same total mass of the carts for each case ($m_A + m_B$ = constant). Rank the collisions from most efficient to least efficient. (Make an educated guess and explain your reasoning.)

Calculate the energy dissipated in a collision in which the carts bounce apart, as a function of the mass of each cart, the initial kinetic energy of the system, and the energy efficiency of the collision. Assuming the kinetic energy of the incoming cart is the same in each case, use your calculation and your educated guess to determine which collision will dissipate the most energy.

WARM UP

Read: Fishbane Chapter 6, sections 6.1-6.2.

The following questions will help you with the calculation part of the prediction and with the analysis of your data.

1. Draw two pictures that show the situation before the collision and after the collision. In this experiment the friction between the carts and the track is negligible. Draw velocity vectors on your sketch. Define your system. Write down the energy of the system before the collision and also after the collision.

2. Write down the energy conservation equation for this collision (Do not forget to include the energy dissipated).

3. Write an equation for the efficiency of the collision in terms of the final and initial kinetic energy of the carts, and then in terms of the cart masses and their initial and final speeds.

4. Solve your equations for the energy dissipated.

5. Use the simulation "Lab3Sim" (See *Appendix F* for a brief explanation of how to use the simulations) to explore the conditions of this problem. For this problem you will want to set the elasticity to something other than zero.

EXPLORATION

Practice setting the cart into motion so that the carts don't touch when they collide. Also, after the collision carefully observe the carts to determine whether or not either cart leaves the grooves in the track. Minimize this effect so that your results are reliable.

Try giving the moving cart various initial velocities over the range that will give reliable results. Note qualitatively the outcomes. Choose initial velocities that will give you useful videos.

Try varying the masses of the carts so that the mass of the initially moving cart covers a range from greater than the mass of the stationary cart to less than the mass of the stationary cart while keeping the total mass of the carts the same. Is the same range of initial velocities useful with different masses? Be sure the carts still move freely over the track. What masses will you use in your final measurement?

MEASUREMENT

Record the masses of the two carts. Make a video of their collision. Examine your video and decide if you have enough positions to determine the velocities that you need. Do you notice any peculiarities that might suggest the data is unreliable?

Analyze your data as you go along (before making the next video), so you can determine how many different videos you need to make, and what the carts' masses should be for each video. Collect enough data to convince yourself and others of your conclusion about how the energy efficiency of this type of collision depends on the relative masses of the carts.

Save all of your data and analysis. You will use it again for Laboratory V.

ANALYSIS

Determine the velocity of the carts before and after the collision using video analysis. For each video, calculate the kinetic energy of the carts before and after the collision.

Calculate the energy efficiency of each collision. Into what other forms of energy do you think the cart's initial kinetic energy is most likely to transform?

Graph how the energy efficiency varies with mass of the initially moving cart (keeping the total mass of both carts constant). What function describes this graph? Repeat for energy efficiency as a function of initial velocity.

CONCLUSION

For which case ($m_A = m_B$, $m_A > m_B$, or $m_A < m_B$) is the energy efficiency the largest? The smallest?

Was a significant portion of the energy dissipated? How does it compare to the case where the carts stick together after the collision? Into what other forms of energy do you think the cart's initial kinetic energy is most likely to transform?

Could the collisions you measured be considered essentially elastic collisions? Why or why not? The energy efficiency for a perfectly elastic collision is 1.

Can you approximate the results of this type of collision by assuming that the energy dissipated is small?

Was your boss right? Does the energy efficiency of a “bouncing” collision seem to depend on the relative masses of the objects? If so, how? State your results that support this conclusion.

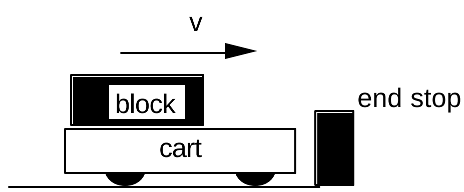
PROBLEM #5:
ENERGY AND FRICTION

You work for an auto company, which has experienced work stoppages when novice forklift drivers stop suddenly, causing crates of auto parts to slide off the forklift and spill on the floor. Your team is investigating the conditions under which such accidents will occur, in order to improve driver training. What factors are important? Your task is to calculate the distance a crate slides after the forklift has come to a sudden stop, as a function of the forklift's initial speed. You assume that the crate is not tied down, and that the surface supporting the crate is horizontal.

To test your prediction, you will model the situation with a cart on the track.

EQUIPMENT

You will have a cart, cart masses, a track, an end stop, a wood / cloth block, a mass set, a meter stick, a stopwatch and the video analysis equipment to determine the velocity of the cart before the collision. You will need to put the cart masses on the top of the cart so that the wood / cloth block can slide on the cart. You can suddenly stop the cart by colliding it with the end stop on the track. Friction between the cart and the track is negligible.



PREDICTIONS

Calculate the distance the block slides in the situation described in the problem as a function of the cart's speed before the collision. Illustrate your prediction graphically.

WARM UP

Read: Fishbane Chapter 6, sections 6.4-6.4.

The following questions will help with the prediction, and analysis of your data.

1. Draw three pictures: one showing the situation just before the collision of the cart with the end-stop, one immediately after the collision when the cart is stopped but the block has not yet begun to slow down, and the third when the wood block has come to rest. Draw velocity vectors on your sketches, and label any important distances. What is the relationship between the cart's velocity and the wood block's velocity in each picture? Define your system. Write down the energy of the system for each picture.

2. Write down the energy conservation equation for this situation, between the second and third pictures. Is any energy transferred into or out of the system?

3. Draw a force diagram for the wood / cloth block as it slides across the cart. Identify the forces that do work on the block (i.e., result in the transfer of energy in or out of the system). Write an equation relating the energy transferred by these forces to the distance the block slides.

4. Complete your prediction, and graph sliding distance vs. initial forklift speed.

EXPLORATION

Practice setting the cart with masses into motion so the cart sticks to the end stop. What adjustments are necessary to make this happen consistently? Place the wood / cloth block on the cart. Try giving the cart various initial velocities. Choose a range of initial velocities that give you good video data. Make sure that the wood / cloth block does not begin to slide on the cart before the collision. Try several masses for the cart and the block. Note qualitatively the outcomes when the cart sticks to the end stop.

MEASUREMENT

Make the measurements that you need to check the prediction. Because you are dealing with friction, it is especially important that you repeat each measurement several times under the same conditions to see if it is reproducible.

ANALYSIS

Make a graph of the distance the block travels as a function of the cart's initial speed. Does this result depends on the mass of the block or the mass of the cart? If the graph is not linear, graph the *distance vs. some power of the speed* to produce a linear graph (see Appendix C). (Use your prediction to guess which power of speed to use.) What is the meaning of the slope of that line?

CONCLUSION

Do your results agree with your predictions? What are the limitations on the accuracy of your measurements and analysis? As a check, determine the coefficient of kinetic friction between the block and the cart from your results. Is it reasonable?

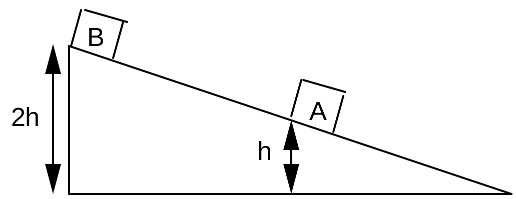
Does the distance that the crate slides depend on the mass of the forklift? On the mass of the crate? If the sliding distance varies linearly with some power of the forklift's initial speed, what is that power? What would you tell forklift drivers about the effect of doubling their speed? In a sentence or two, relate this result to conservation of energy.

☑ CHECK YOUR UNDERSTANDING:

1. A 1kg ball dropped from a height of 2 meters rebounds only 1.5 meters after hitting the floor. The amount of energy dissipated during the collision with the floor is:

   (a) 5 joules.
   (b) 10 joules.
   (c) 15 joules.
   (d) 20 joules.
   (e) More than 20 joules.

2. Two boxes start from rest and slide down a *frictionless* ramp that makes an angle of 30^o with the horizontal. Block A starts at height h, while Block B starts at a height of 2h.



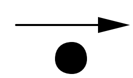
   a. Suppose the two boxes have the same mass. At the bottom of the ramp,

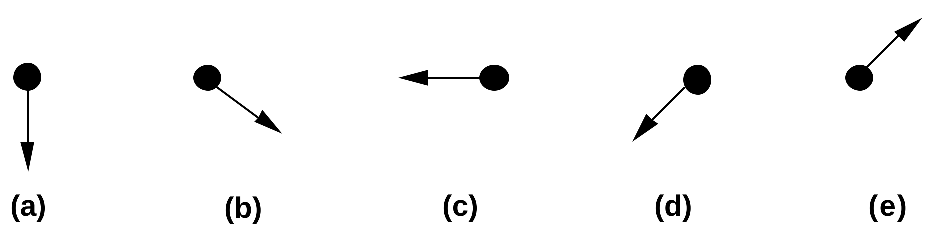
   (a) Box A is moving twice as fast as box B.
   (b) Box B is moving twice as fast as box A.
   (c) Box A is moving faster than box B, but not twice as fast.
   (d) Box B is moving faster than box A, but not twice as fast.
   (e) Box A has the same speed as box B.

   b. Suppose box B has a larger mass than box A. At the bottom of the ramp,

   (a) Box A is moving twice as fast as box B.
   (b) Box B is moving twice as fast as box A.
   (c) Box A is moving faster than box B, but not twice as fast.
   (d) Box B is moving faster than box A, but not twice as fast.
   (e) Box A has the same speed as box B.

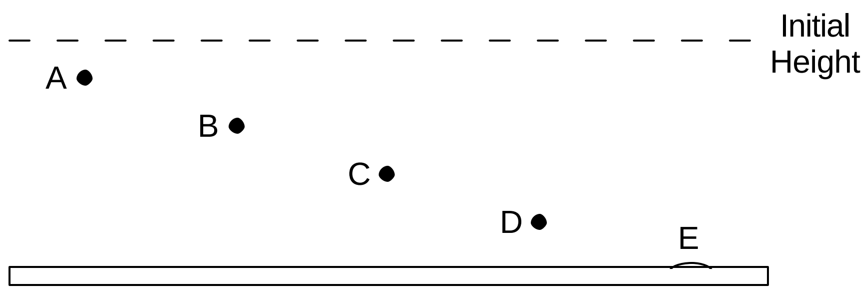
3. A hockey puck is moving at a constant velocity to the right, as shown in the diagram. Which of the following forces will do *positive* work on the puck (i.e., cause an *input* of energy)?





☑ CHECK YOUR UNDERSTANDING

4. Five balls made of different substances are dropped from the same height onto a board. Four of the balls bounce up to the maximum height shown on the diagram below. Ball E sticks to the board.



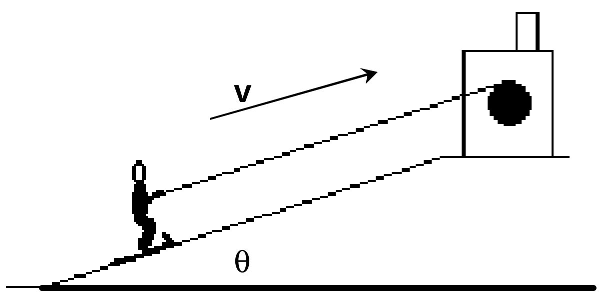
a. For which ball was the most energy dissipated in the collision?

(a) Ball A
(b) Ball B
(c) Ball C
(d) Ball D
(e) Ball E

b. Which ball has the largest energy efficiency?

(a) Ball A
(b) Ball B
(c) Ball C
(d) Ball D
(e) Ball E

5. A skier is pulled a distance x up a hill at a constant velocity by a towrope. The coefficient of friction between the skis and the snow is ? $_k$.



a. Draw a force diagram of the skier. Which of the forces acting on the skier do positive work (i.e., cause an input of energy). Which of the forces do negative work (i.e., cause an output of energy)? Explain your reasoning.

b. Based on the definition of work, write an expression for the positive work done on the skier (i.e., the energy input). Write an expression for the negative work done on the skier (i.e., the energy output).

c. Which is larger, the positive work done on the skier or the negative work done on the skier? Or are they the same size? Explain your reasoning?

TA Name:____________________________

PHYSICS 1301 LABORATORY REPORT

Laboratory IV

Name and ID#: ____

Date performed: ______________ Day/Time section meets: ______________________

Lab Partners' Names: ____

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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 <u>rewrite that section only</u> and return it to your lab instructor within two days of the return of the report to you.