LABORATORY V
CONSERVATION OF MOMENTUM

In this lab you will use *conservation of momentum* to predict the motion of objects resulting from collisions. It is often difficult or impossible to obtain enough information for a complete analysis of collisions in terms of forces. Conservation principles can be used to relate the motion of objects before a collision to motion after the collision without knowledge of the complicated details of the collision process itself, but conservation of energy alone is usually not enough to predict the outcome. To fully analyze a collision, one must often use both conservation of energy *and* conservation of momentum.

OBJECTIVES:

Successfully completing this laboratory should enable you to:

- Use conservation of momentum to predict the outcome of interactions between objects.
- Choose a useful system when using conservation of momentum.
- Identify momentum transfer (impulse) when applying momentum conservation to real systems.
- Use the principles of conservation of energy and of momentum together to describe the behavior of systems.

PREPARATION:

Read Paul M. Fishbane: Chapter 8. You should also be able to:

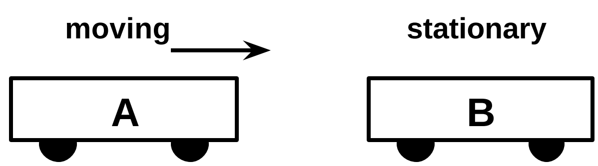
- Analyze the motion of an object using video analysis.
- Calculate the work transferred to or from a system by an external force.
- Calculate the total energy of a system of objects.
- Calculate the total momentum of a system of objects.

PROBLEM #1:
PERFECTLY INELASTIC COLLISIONS

You work for NASA with a group designing a docking mechanism that would allow two space shuttles to connect with each other. The mechanism is designed for one shuttle to move carefully into position and dock with a stationary shuttle. Since the shuttles may be carrying different payloads and different amounts of fuel, their masses may not be identical: the shuttles could be equally massive, the moving shuttle could be more massive, or the stationary shuttle could have a larger mass. Your supervisor wants you to calculate the magnitude and direction of the velocity of the pair of docked shuttles, as a function of the initial velocity of the moving shuttle and the mass of each shuttle. You may assume that the total mass of the two shuttles is constant. You decide to model the problem in the lab using carts to check your predictions.

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. Pads at the end of each cart allow the carts to stick together after the collision. Video analysis equipment is available. You will also need a meter stick, a stopwatch, two end stops and cart masses.



PREDICTION

Restate the problem to identify your target and get the relationships useful for the three cases considered in the problem.

WARM UP

Read: Fishbane Chapter 8, sections 8.1-8.3.

The following questions are designed to help you with your prediction and the analysis of your data.

1. Make two drawings that show the situation (a) before and (b) after the collision. Show and label velocity vectors for each object in your drawings. If the carts stick together, what must be true about their final velocities? Define your system.

2. Write down the momentum conservation equation for the system; identify all of the terms in the equation. Are there any of these terms that you cannot measure with the equipment at hand? Is the momentum of the system conserved during the collision? Why or why not?

3. Write down the energy conservation equation for the system; identify all the terms in the equation Are there any of these terms that you cannot measure with the equipment at hand? Is the energy of the system conserved? Why or why not? Is the *kinetic* energy of the system conserved? Why or why not?

4. Which conservation principle should you use to predict the final velocity of the stuck-together carts, or do you need both equations? Why?

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

If you have done Problem #3 in Lab IV, you should be able to skip this part.

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? What masses will you use in your final measurement?

MEASUREMENT

If you have done Problem #3 in Lab IV, you should be able to skip this part and just use the data you have already taken. Otherwise make the measurements outlined below.

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 final velocity of both carts in this type of collision depends on velocity of the initially moving cart and the masses of the carts.

ANALYSIS

Determine the velocities of the carts (with uncertainty) before and after each collision from your video. Calculate the momentum of the carts before and after the collision.

Now use your Prediction equation to calculate each final velocity (with uncertainty) of the stuck-together carts.

CONCLUSION

How do your measured and predicted values of the final velocity compare? Compare both magnitude and direction. What are the limitations on the accuracy of your measurements and analysis?

When a moving shuttle collides with a stationary shuttle and they dock (stick together), how does the final velocity depend on the initial velocity of the moving shuttle and the masses of the shuttles? State your results in the most general terms supported by the data.

What conditions must be met for a system's *total momentum* to be conserved? Describe how those conditions were or were not met for the system you defined in this experiment. What conditions must be met for a system's *total energy* to be conserved? Describe how those conditions were or were not met for the system you defined in this experiment.

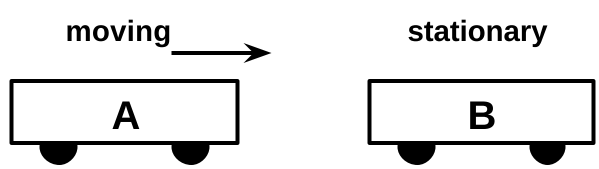
PROBLEM #2:
ELASTIC COLLISIONS

You are still working for NASA with the group designing a docking mechanism that would allow two space shuttles to connect with each other. The mechanism is designed for one shuttle to move carefully into position and dock with a stationary shuttle. Since the shuttles may be carrying different payloads and have consumed different amounts of fuel, their masses may be different when they dock: the shuttles could be equally massive, the moving shuttle could be more massive, or the stationary shuttle could have a larger mass.

Your supervisor wants you to consider t case which could result from the pilot missing the docking mechanism or the mechanism failing to function. In this case the shuttles gently collide and bounce off each other. Your supervisor asks you to calculate the final velocity of both shuttles as a function of (a) the initial velocity of the initially moving shuttle, (b) the masses of both shuttles, and (c) the fraction of the moving shuttle's initial kinetic energy that is *not dissipated* during the collision (the "energy efficiency"). You may assume that the total mass of the two shuttles is constant. You decide to check your calculations in the laboratory using the most efficient bumper you have, a magnetic bumper.

EQUIPMENT

You will use the same equipment as in Problem #1m except that magnets will be used to bounce the carts apart after the collision. Masses can be added to the top of either cart. The video analysis equipment is available. You will also need a meter stick, a stopwatch, two end stops and cart masses.



PREDICTION

Restate the problem such that you understand and identify its goal then get the equations necessary to test your lab model.

WARM UP

Read: Fishbane Chapter 8, sections 8.1-8.2 and 8.4.

The following questions are designed to help you with your prediction and the analysis of your data.

1. Draw two pictures that show the situation before the collision and after the collision. Draw velocity vectors on your sketch. If the carts bounce apart, do they have the same final velocity? Define your system.

2. Write down the momentum of the system before and after the collision. Is the system's momentum conserved during the collision? Why or why not?

3. If momentum is conserved, write the momentum conservation equation for this situation; identify all of the terms in the equation.

4. Write down the energy of the system (a) before and (b) after the collision.

5. Write down the energy conservation equation for this situation and identify all the terms in the equation.

6. Write the expression for the energy dissipated in the collision in terms of the energy efficiency and the initial kinetic energy of the system (see Laboratory IV, Problem #4). Can you assume that no energy will be converted into internal energy?

7. Solve the equations you wrote in previous steps to find the final velocity of each cart in terms of the cart masses, the energy efficiency of the collision, and the initial speed of the moving cart. *Warning: the algebra may quickly become unpleasant! Stay organized.*

8. 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

If you have done Problem #4 in Lab IV, you should be able to skip this part.

Practice setting the cart into motion so that the carts don't touch when they collide.. 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. Keep in mind that you want to choose an initial velocity that gives you a good video.

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. Be sure the carts still move freely over the track. What masses will you use in your final measurement?

MEASUREMENT

If you have done Problem #4 in Lab. IV, you should be able to skip this part and just use the data you have already taken. Otherwise make the measurements outlined below.

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 final velocities of both carts in this type of collision depend on the velocity of the initially moving cart, the masses of the carts, and the energy efficiency of the collision.

ANALYSIS

Determine the velocities of the carts (with uncertainty) before and after each collision from your video. Calculate the momentum and kinetic energy of the carts before and after the collision.

If you have the results from Lab IV, Problem 4, use the appropriate energy efficiency you determined for the collision from that problem. If not, calculate the energy efficiency of each collision from the initial and final kinetic energy of the system. Graph how the energy efficiency varies with mass of the initially moving cart (keeping the total mass of both carts constant). What is the function that describes this graph? Repeat this for energy efficiency as a function of initial velocity. Can you make the approximation that no energy goes into internal energy of the system (energy efficiency = 1)?

Now use your Prediction equation to calculate the final velocity (with uncertainty) of each cart, in terms of the cart masses, the initial velocity of the moving cart, and the energy efficiency of each collision.

CONCLUSION

Did your measurement agree with your prediction? Why or why not? Was the collision perfectly elastic in the three different cases? What are the limitations on the accuracy of your measurements and analysis?

What conditions must be met for a system's *total momentum* to be conserved? Describe how those conditions were or were not met for the system you defined in this experiment. What conditions must be met for a system's *total energy* to be conserved? Describe how those conditions were or were not met for the system you defined in this experiment.

☑ CHECK YOUR UNDERSTANDING

1 If a runner speeds up from 2 m/s to 8 m/s, the runner's *momentum* increases by a factor of

(a) 64.
(b) 16.
(c) 8.
(d) 4.
(e) 2.

2. A piece of clay slams into and sticks to an identical piece of clay that is initially at rest. Ignoring friction, what percentage of the initial kinetic energy goes into changing the internal energy of the clay balls?

(a) 0%
(b) 25%
(c) 50%
(d) 75%
(e) There is not enough information to tell.

3. A tennis ball and a lump of clay of equal mass are thrown with equal speeds directly against a brick wall. The lump of clay sticks to the wall and the tennis ball bounces back with one-half its original speed. Which of the following statements is (are) true about the collisions?

(a) During the collision, the clay ball exerts a larger average force on the wall than the tennis ball.
(b) The tennis ball experiences the largest change in momentum.
(c) The clay ball experiences the largest change in momentum.
(d) The tennis ball transfers the most energy to the wall.
(e) The clay ball transfers the most energy to the wall.

4. A golf ball is thrown at a bowling ball so that it hits head on and bounces back. Ignore frictional effects.

a. Just after the collision, which ball has the largest momentum, or are their momenta the same? Explain using vector diagrams of the momentum before and after the collisions.

b. Just after the collision, which ball has the largest kinetic energy, or are their kinetic energies the same? Explain your reasoning.

5. A 10 kg sled moves at 10 m/s. A 20 kg sled moving at 2.5 m/s has:

(a) 1/4 as much momentum.
(b) 1/2 as much momentum.
(c) twice as much momentum.
(d) four times the momentum.
(e) None of the above.

☑ CHECK YOUR UNDERSTANDING

6. Two cars of equal mass travel in opposite directions with equal speeds on an icy patch of road. They lose control on the essentially frictionless surface, have a head-on collision, and bounce apart.

a. Just after the collision, the velocities of the cars are:

(a) zero.
(b) equal to their original velocities.
(c) equal in magnitude and opposite in direction to their original velocities.
(d) less in magnitude and in the same direction as their original velocities.
(e) less in magnitude and opposite in direction to their original velocities.

b. In the type of collision described above, consider the system to consist of both cars. Which of the following can be said about the collision?

(a) The kinetic energy of the system does not change.
(b) The momentum of the system does not change.
(c) Both momentum and kinetic energy of the system do not change.
(d) Neither momentum nor kinetic energy of the system change.
(e) The extent to which momentum and kinetic energy of the system do not change depends on the coefficient of restitution.

7. Ignoring friction and other external forces, which of the following statements is (are) true just after an arrow is shot from a bow?

(a) The forward momentum of the arrow equals that backward momentum of the bow.
(b) The total momentum of the bow and arrow is zero.
(c) The forward speed of the arrow equals the backward speed of the bow.
(d) The total velocity of the bow and arrow is zero.
(e) The kinetic energy of the bow is the same as the kinetic energy of the arrow.

☑ CHECK YOUR UNDERSTANDING

TA Name:__________________________

PHYSICS 1301 LABORATORY REPORT

Laboratory V

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