Collisions and Damage:

Momentum and Energy

You are working with the Minnesota Highway Patrol over the summer. One of your projects is to help investigators reconstruct accidents. In one scenario, a car is stopped at a red light and is rear-ended by an inattentive driver. The inattentive driver is obviously at fault in this accident but witnesses also say that the driver was speeding before the accident. To accurately prosecute this case, you are asked to find the driver’s velocity before the impact.

The collision was so catastrophic that the two cars stuck together and traveled into the intersection. Based on the length of the skid marks, the type of road, and the type of tires on the cars, you can estimate the speed that the two cars had *immediately after the collision* (before the effects of friction slowed the cars down appreciably). You then further investigate collisions and realize that using the concepts of momentum and energy you can calculate the velocity of the inattentive driver before the collision.

**Safety**: There are no significant safety concerns for this lab. General lab safety should be followed.

**Pre-lab:** Include the experiment name, the purpose of the experiment, and the major experimental steps used to achieve this purpose.

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| Top View: Just before the collision | Top View: Just after the collision |

**General Information on Momentum to help you complete this lab**: (Also, see notes and lecture resource material.)

* Momentum is defined as the mass of an object multiplied by its velocity. p = mv
* From *Newton’s 2nd Law* of motion we know that forces can change momentum. More precisely, the change in momentum (of the object) divided by the time (that the force acts) is equivalent to the force on the object: . Here,  represents the change in momentum: 
* Finally, *Newton’s 3rd Law* says that when two objects exert a force on one another (like in a collision when the two cars exert forces on one another), those two forces are equal an opposite. In other words, the force that object 1 exerts on object 2 (i.e. F1\_on\_2) is equal but opposite in direction to the force that object 2 exerts on 1 (i.e. F2\_on\_1). Thus F1\_on\_2 = - F2\_on\_1 (the negative sign means it is in opposite direction)

So, let’s put all these together. During the collision we can write for car 2 that  (eqn 1) and likewise we can write for car 1:  (eqn 2). Now, from Newton’s 3rd law (from above), we know that F1\_on\_2 = - F2\_on\_1 (eqn3). Sub in eqn 1 for the right-hand-side of eqn 3 and sub in eqn 2 for the left-hand-side of eqn3. Then eqn 3 becomes: . The time cancels out from both side and we have . Which (given that ) we can rewrite as p2a – p2b = -(p1a – p1b). [here, “a” means “after collision” and “b” means “before” and the “1” and “2” refer to car 1 and 2]. And we can take this one step further and rearrange terms using algebra to get:

(eqn 4, momentum conservation) p2a + p1a = p1b + p2b.

In other words, the momentum “before” the collision of the two cars added together must equal the momentum of the two cars “after”. *This is the law of conservation of momentum*

We can apply this conservation law and the definition of momentum, to the problem for this lab. Using the *well labeled* diagram from above we can write eqn 4 as

m2vf + m1vf = m1vinit

**Background on Energy**

Energy is a very abstract concept yet it is very important. The more energy you add to a system, the more it will change. For example, if you add energy to water by heating it, eventually it will boil and turn into a vapor. Well, the same idea holds true in collisions. The more energy that is transferred during the collision will mean that there is more change => and for a collision this ‘change’ is manifested by the damage of the vehicles (i.e. changing the shape of the car!)

The energy of an object that is moving is called “kinetic energy” and is related to the velocity as well as the mass of the object. Why? Well, certainly if it is moving faster, it is more likely to cause ‘change’ when it collides. In fact, it is possible to prove that this *energy of motion* is: KE = ½ mv2.

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| **?** | In terms of the final velocity and the masses of the two carts, what is initial velocity of the moving car? |

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| Equipment  * A track * A level * Two carts * Extra masses * “Picket Fences” for carts * 2 Photogates with Timer and power supply * Clamps and posts for Photogates |  |

**Exploration**

Any good scientific experiment always starts with the experimenter determining the limits of their equipment. In other words, you need to determine what you can accurately measure with the given equipment.

First, explore the track with one cart. Place the cart on the track. Does the cart move? What does this imply about how level the track is?

Level the track and practice giving the cart a push. First, give it a fast push and observe the equipment. Next, give it a slow push and observe. What does the cart do? Does it slow down? Does it move at a roughly constant speed? How will the results of this exploration effect how you interpret the data for this lab?

Now, set up the experiment with a moving cart colliding into a stationary cart. To make sure that they stick together after the collision, use the ends of the carts that have Velcro on them. Note that some of the carts also have magnets in them and they might repel one another => try to avoid this => pick another pair of carts.

Before collecting data, practice colliding the carts. Try it under several conditions:

* With m1 = m2
* With m1 > m2
* With m1 < m2.

From your observations answer the following:

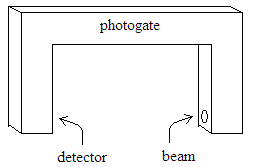
* Under which of these three conditions does cart 1 have the smallest change in momentum?
* Under which condition does it have the largest change in momentum?

Do your answers make sense to what you have experienced in the past?

Now, practice taking data and calculating the cart’s velocity. To do this, you will use a “Photogate”.

*Photogates*

On the Photogate is a light beam emitted on one end with a detector on the other. The beam is shot toward the detector.



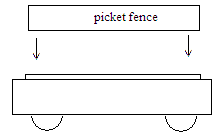
Since we are measuring two velocities at two different places on the track, you will need two Photogates. A second Photogate can interface with the Timer via a plugin on the side.

*Timer*

There are several features on the Timer itself. Use the Timer in “gate” mode. In this mode, when something blocks the light beam from getting to the detector, the Timer starts. When it is unblocked again, the Timer stops. Try this with your hand to confirm that the detector is working properly.

*How to use the Photogate and Timer together to get velocity*

A “picket fence” is supplied that has patterns of clear and black-out portions of the fence. Properly place the picket fence in the cart (there are groves on the top side of the cart that allow you to insert the fence vertically).



You will need to lower the Photogates until the beam can be broken by one of the long blacked-out portions of the fence. This blacked-out portion will start and stop the Timer as it goes through the Photogate.

When two Photogates are hooked up to the Timer, you can get time information from both gates by using the “Memory” function. How? Well, turn the Memory function “on”. When the first gate is blocked, the Timer starts. When it is unblocked, the Timer stops. The Timer will then display the recorded time. When the second Photogate is activated, the display will not change, however, the Timer does record the time for the second gate. But it does not record just the time for the second gate, it records the time for both gates and keeps it in the Memory. To access the second time, click the Memory button to “read”. Once you do this, you will lose the information from the first Photogate so please make sure you record it.

Here is an example of the time you might get:

* Photogate 1 is blocked and then unblocked. The Timer reads “0.147 seconds”
* Photogate 2 is blocked and then unblocked. The Timer display hasn’t changed
* Hit the Read button. The Timer displays, “0.457 s”. This means that the 2nd Photogate was blocked for a time of 0.457 – 0.147 seconds = 0.31 seconds.

Finally, given the operation of the Photogates & Timer and the length of the blacked-out portion of the picket fence, make a plan on how you can measure velocity of the carts before and after the collision. Record the plan in your notebook.

Where will you place the Photogates?

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Try collecting some data to see if you plan might work.

**Data Analysis and Results.**

When you are confident that you have a plan for collecting velocity data, try the experiment and see if you can accurately predict the initial velocity of the cart. Remember, you can use the equation m2vf + m1vf = m1vinit to actually *predict* the carts initial velocity after you have measured the carts final velocity and their masses. Then, you can *compare your prediction to the measured* value of cart 1’s initial velocity.

Try to see if you can accurately predict cart 1’s initial velocity for all possible scenarios of a crash:

* With m1 = m2
* With m1 > m2
* With m1 < m2.

Investigator #1 \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Investigator #2 \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Lab Report Form to be turned in for grading**

**Pre-lab:**

1. What is the purpose of this experiment? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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1. What are the major experimental steps used to achieve this purpose? \_\_\_\_\_\_\_

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Pre-lab instructor signature: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Lab**  Pages in lab notebook that observations can be found on \_\_\_\_\_\_\_\_\_\_

1. Will cart 1 have the smallest change in momentum when m1 = m2, m1 > m2, or m1 < m2? How do you know? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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1. Which of the above three conditions will cause the largest change in momentum? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ How do you know? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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1. Do the answers to #1 and #2 make sense with what you have experienced in your life prior to this class? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Give a specific example. \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
2. Page in lab notebook experimental plan for how you will measure the velocity of the carts before and after the collision with the photogates \_\_\_\_\_\_\_\_\_\_\_\_\_
3. Can you predict the initial velocity of a car if it collides with a stationary car given the masses of the two cars and the final velocity of the two cars? How?

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1. Is momentum conserved in your collision? What are some possible effects that might have caused some uncertainty in your experiment? \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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1. Your friend was in a car accident in which she was stationary and trying to turn left when a car collided with her from behind. The driver of the other car claims that he was going 40 mph just before the collision but you suspect that he was speeding (the posted speed limit is 40 mph). The accident investigator deduces that immediately after you were hit, both cars moved together at a speed of 30 mph before coming to rest. If your friend’s car has a mass of 1000 kg and the mass of the other car is 1200 kg, was the driver of the other car speeding? What speed were they going? (By the way, of course the other driver is at fault in this whether he is speeding or not.)
2. A large truck collides with a parked compact car. The compact car is totaled in the collision (but luckily no one was in the car at the time)
3. The truck exerts a larger force on the car than the car exerts on the truck
4. The car exerts a larger force on the truck than the truck exerts on the car
5. The car exerts the same force on the truck as the truck exerts on the car
6. The car exerts no force on the truck because the car is being squashed.

Explain your choice.

**How is physics** used to reconstruct automobile accidents? Please cite any references you used in your answer.