

Collision

Goals: Use multiple electronic measuring devices to get related data. Propagate errors from multiple devices. Identify the effects of frictional losses in a system.

APPARATUS

A collision occurs when two objects interact with each other for a short time. During that time each object exerts a force on the other. Collisions are used to model everything from molecules in a gas to trick shots in billiards to accidents on a freeway. Collisions can involve more than one dimension, but in this case we will restrict our study to collisions in only one dimension. A spectacular example of a one-dimensional collision is the 1896 train crash at Crush, Texas (photo from The Dallas Morning News Archive).



We will study collisions on a track, though not as spectacular as the one at Crush. The trains will be replaced by rolling carts powered by a simple push and the carts can be equipped to either bounce off each other in an elastic collision or stick together for a completely inelastic collision.

An ideal track would be without friction, but friction can be minimized with well lubricated and aligned wheels on a cart. The track must also be level to negate any effects of gravity. There are two carts: a large cart of mass (m_1) and length (l_1) and a small cart of mass (m_2) and length (l_2). The carts use repulsive magnets to provide elastic collisions. The carts can also be positioned with velcro between them to create completely inelastic collisions.

A metal “flag” is attached to each cart which will block a photogate beam. Two photogates are positioned over the track and can measure the time (t) that a cart passes through the beam. The times can be read from the LoggerPro software when the photogates are attached to the computer. The photogates record the elapsed time between the time the flag blocks the beam until it is no longer blocked, but not the direction of motion. The experimenter must determine the direction of motion.

THEORY

Velocity is the time rate of change of position of an object. If the length of an object and the time it takes to pass a point are both known the velocity is

$$v = \frac{l}{t} \quad (\text{EQ 1})$$

The sign of the velocity depends on the direction of the object. If it is moving in the positive direction the velocity is positive, and if it is moving in the negative direction, the velocity is negative. An object at rest has a velocity of 0.

Momentum (p) is the product of mass (m) and velocity (v). Since velocity is a vector and has direction, so does momentum. For two or more interacting objects, the total momentum is just the sum of the individual momenta. For two masses (m_1 and m_2) and velocities (v_1 and v_2) moving only in one dimension, the total momentum (P) is

$$P = p_1 + p_2 = m_1v_1 + m_2v_2 \quad (\text{EQ 2})$$

If there are no forces acting on a set of objects other than the interaction between them, the system is called an *isolated system*. In any isolated system the total momentum of a set of objects is constant. We say that the total momentum in an isolated system is *conserved*. During a collision the time is so short that external forces do not have much affect on the momentum of the system. This allows us to describe all collisions as isolated systems and apply conservation of momentum. If the initial total momentum is P_i and the final total momentum is P_f , conservation of momentum is $P_i = P_f$.

Objects in motion also possess kinetic energy. Kinetic energy (K) is a scalar quantity that is never negative. It also depends on the mass and velocity according to

$$K = \frac{1}{2}mv^2 \quad (\text{EQ 3})$$

Like total momentum the total kinetic energy of a system is just the sum of the individual kinetic energies. For a system of two objects the total kinetic energy is

$$K = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 \quad (\text{EQ 4})$$

In certain collisions between objects that only involve a conservative force such as an ideal spring, the initial total kinetic energy K_i equals the final total kinetic energy K_f . This type of collision is called an *elastic* collision.

Other collisions are called *inelastic* and involve some loss of energy during the collision. The final total kinetic energy is always less than the initial total kinetic energy of the system. A completely inelastic collision occurs when the two objects collide and stick together. This means that the two objects leave the collision with identical velocities (v_f). We can write EQ 2 for a completely inelastic collision as

$$m_1v_{1i} + m_2v_{2i} = m_1v_f + m_2v_f = (m_1 + m_2)v_f \quad (\text{EQ 5})$$

In real systems the collisions involve some friction which can cause a loss of kinetic energy in elastic collisions. For all collisions there is friction on the track just before and after the collision, which prevents the system from being truly isolated and can result in a loss of momentum and energy. We can judge the amount of loss for a physical quantity by looking at the percent change in that quantity compared to the initial value. EQ 6 and EQ 7 show formulas for measuring momentum loss and kinetic energy loss respectively.

$$\frac{\Delta P}{P_i} = \left(\frac{P_f - P_i}{P_i} \right) \cdot 100\% \quad (\text{EQ 6})$$

$$\frac{\Delta K}{K_i} = \left(\frac{K_f - K_i}{K_i} \right) \cdot 100\% \quad (\text{EQ 7})$$

DATA COLLECTION

1. Measure and record the cart masses (m_1 and m_2) and flag lengths (l_1 and l_2) for the carts. The heavy cart is the one with a plunger that has a magnetically attached mass on top. The light cart has a small magnet attached to one end and velcro on the other end. Use the level to check that the track is horizontal.
2. Check that the computer is on, and confirm that LabPro is connected to the computer and to both photogates. Note which photogate is plugged in DIG/SONIC 1 and which is plugged into DIG/SONIC 2.
3. Open LoggerPro on the computer. If needed use **Set Up Sensors** to set both **DIG/SONIC 1** and **DIG/SONIC 2** to *Photogate*.
4. From the **Experiment** pull-down menu, select **Extend Collection**, and repeat until the time shown by **Extend Selection** is greater than 100 s.
5. You should see three graphs appear, and they may pop up automatically when Logger Pro is started. Click on each graph and hit the **delete** key. Expand the data table so it is easier to see all the data points. DIG/SONIC 1 will appear as *Port 1*.
6. Confirm that the red light on each photogate flashes as the cart passes through the photogate.

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7. Place the heavy cart at one end of the track so that end without the plunger is pointed towards the other end of the track.
 8. Start LoggerPro with the “Start Collection” button, and make a trial run by pushing the heavy cart firmly enough to pass through both photogates, but be sure to catch the cart before it goes off the end of the track. Record the times from LoggerPro.
 9. Place the light cart in the middle of the track with the magnet facing the heavy cart. Make another trial run to see the magnet work to avoid contact between the carts.
 10. Place the heavy cart at one end, and start LoggerPro. Push the heavy cart through the first photogate toward the light cart. After the light cart passes through the second gate lift it off the track before the heavy cart passes through the photogate.
 11. After the heavy cart passes through the second photogate, lift it off the track. Record the first time from the first photogate, and both times from the second photogate.
 12. Repeat steps 9 through 11 with the heavy cart in the middle and the light cart pushed from one end of the track.
 13. Place the light cart in the middle of the track with the velcro facing the heavy cart. Make a trial run to see that the velcro causes the carts to stick together.
 14. Place the heavy cart at one end, and start LoggerPro. Push the heavy cart through the first photogate toward the light cart. Make sure both flags completely pass through the second photogate.
 15. After the heavy cart passes through the second photogate, record the first time from the first photogate, and both times from the second photogate.
 16. Repeat steps 13 through 15 with the heavy cart in the middle and the light cart pushed from one end of the track.

DATA ANALYSIS

17. Find the velocity of the large cart through each photogate taken in step 8 using EQ 1. Include a calculation of the error on the velocity.
18. Find the kinetic energy and its error for the large cart using EQ 3 for each velocity calculated in step 17. Find the change in kinetic energy from the initial to the final values, K_i and K_f .
19. For each collision (steps 11, 12, 15, and 16), use the length and time information to find the velocity (with EQ 1) of each cart before the collision and after the collision. Include a calculation of the error on each velocity you record.
20. Find the total momentum and its error for the carts before P_i and after P_f each collision using EQ 2, or EQ 5 in the case of the final momentum from the collisions in step 15 and 16.
21. For each collision find the change in total momentum as a percentage of the total using EQ 6.
22. Find the total kinetic energy and its error for the carts before K_i and after K_f each collision using EQ 4.
23. For each collision find the change in total kinetic energy as a percentage of the total using EQ 7.
24. Your TA will assign an addition question or two to answer in the report. This work should be done by each group member individually.
25. Each student should assemble a single report from the group data report and the additional individual question. This report will be turned in for grading.