

# Conservation of Momentum and Energy

## Objectives

- to investigate simple elastic and inelastic collisions in one dimension in order to study the laws of conservation of momentum and conservation of energy

## Equipment

horizontal dynamics track, collision and dynamics carts with picket fences, photogates connected to the Science Workshop Interface, level, additional weights (masses)



Figure 1

## Introduction and Theory

Collisions are an important way of studying how objects interact. Conservation laws have been developed that allow one to say quite a bit about what is happening without knowing the exact details of the interaction during the collision. In this lab, you will show that the total momentum of the system is always conserved when there is no net external force acting on the system, and that the total mechanical energy of the system is only conserved in certain kinds of collisions. These principles are important in studying automobile collisions, planetary motion, and the collisions of subatomic particles.

Momentum is the product of mass ( $m$ ) and velocity ( $\mathbf{v}$ ), so it has the units of  $\text{kg} \cdot \text{m}/\text{sec}$ . Momentum is a **vector** quantity with its direction the same as the velocity. We do not have a special name for the unit of momentum, but we do commonly use the letter  $\mathbf{p}$  to represent the momentum vector.

$$\mathbf{p} = m \cdot \mathbf{v} \tag{1}$$

**Conservation of Momentum:** In a closed system, momentum is conserved when objects are interacting with each other. A closed system (or isolated system) is a system in which objects are considered to interact only with each other, and do not exchange any matter/energy with their surroundings.

In this experiment, we will be dealing with elastic and inelastic collisions in one dimension.

The motion of the bodies involved is constrained to a horizontal track (Fig. 1). This means that the velocity and momentum vectors can be only in one of two directions,  $+x$  or  $-x$ , where  $x$  represents the coordinate along the track. Since we will be dealing with only two bodies, the Law of Conservation of Momentum can be written as

$$\Sigma \mathbf{p}_{ix} = \Sigma \mathbf{p}_{fx} \quad (2)$$

where  $\Sigma \mathbf{p}_{ix}$  is the total initial momentum of the system, and  $\Sigma \mathbf{p}_{fx}$  is the total final momentum of the system. This can be expressed for two bodies as

$$m_1 \mathbf{v}_{1ix} + m_2 \mathbf{v}_{2ix} = m_1 \mathbf{v}_{1fx} + m_2 \mathbf{v}_{2fx}. \quad (3)$$

Another important conservation law is the **Conservation of Mechanical Energy**. Energy is a scalar quantity and not a vector. A scalar quantity has just a magnitude and no direction. Energy is the ability of an object to do work. The unit of energy is the Joule (J). Two major forms of mechanical energy are potential and kinetic. Kinetic energy ( $K$ ) is the energy of motion and is defined as

$$K = \frac{1}{2}mv^2. \quad (4)$$

Potential energy ( $U$ ) is stored energy. In the special case of gravitational potential energy, an object is moving under the influence of the constant gravitational force. Gravitational potential energy ( $U_g$ ) is a function of the position and mass and is defined as

$$U_g = mgy. \quad (5)$$

Mechanical energy is conserved depending on whether the forces between the interacting objects are conservative.

Examples of conservative forces are gravity, electric, and magnetic forces. There are other forces at the level of nuclear physics that are also conservative. The most important nonconservative force we will deal with is friction. Friction is a nonconservative force because energy is converted into heat by friction. Another example of a nonconservative “force” will occur when we have two bodies that collide and stick together. This will be a special case of friction where the energy will be converted into internal energy in the process of sticking together.

In this experimental setup, to see if mechanical energy is conserved, we must evaluate only the kinetic energy before and after the collision. There is no change in the gravitational potential energy in this case because the motion takes place on a level surface (Fig. 1) and therefore  $y$ —vertical position—does not change. In this case, the conservation of mechanical energy can be expressed with the following equation.

$$\frac{1}{2}m_1v_{1i}^2 + \frac{1}{2}m_2v_{2i}^2 = \frac{1}{2}m_1v_{1f}^2 + \frac{1}{2}m_2v_{2f}^2 \quad (6)$$

An **elastic collision** is defined as one in which the kinetic energy is conserved (as well as the momentum). If the collision is **inelastic**, then the only conservation law that is applicable is the conservation of momentum. In the case of a **perfectly inelastic collision** when objects stick together after the collision, a maximum amount of kinetic energy is lost.

In this lab, you will investigate the elastic and perfectly inelastic collisions and define the types of collisions for which the Law of Conservation of Momentum and/or Law of Conservation of Energy holds true.

**Important:** If the percent lost in momentum is less than 12%, then the Law of Conservation of Momentum holds true. If the percent lost in energy is less than 25%, then the Law of Conservation of Energy holds true and the collision is elastic. If the lost energy is more than 25%, then the collision is either elastic or inelastic.

Thus, discuss with your group members what data needs to be collected in order to prove conservation of momentum and/or conservation of energy. Login to your WebAssign account and print the worksheet for this lab. Open the Conservation of Momentum and Energy Inlab to enter your answers.

## Video

View the video online prior to beginning your lab.

A video or simulation is available online.

## Procedure

Please print the worksheet for this lab.

### CHECKPOINT:

Be sure to have your TA sign your lab worksheet, printed Inlab, and all printed graphs after each part is completed. Be sure the data can be seen on the graphs.

The experimental setup is depicted in Figs. 1 and 2. The two photogates will record the position of the carts as a function of time. This is done by using picket fences of known band spacing (see Appendix B).

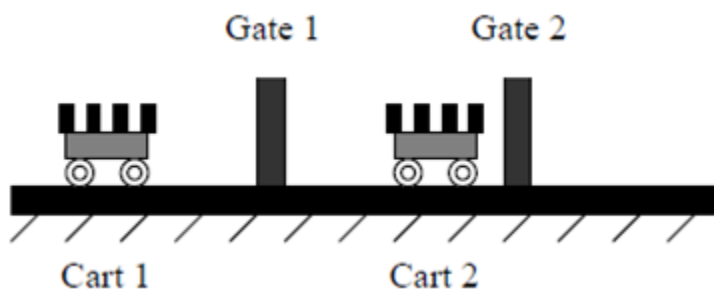


Figure 2

- 1 Make sure that the photogate light beam is level with the **1-cm-spaced bands**.

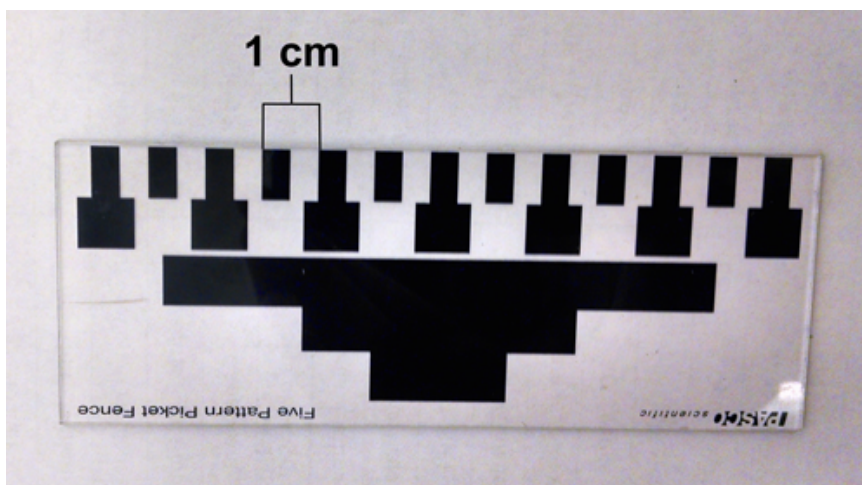


Figure 3

Open the preset experiment file: *Labs/PHY 113/PreSetUp Labs/Conservation of Momentum*. Make sure the **Start** button is active. The recording has to be started and stopped manually in this experiment. After each run, do a print screen and save the graphs as a file with a maximum size of 1 MB. (You will upload this file in the WebAssign Inlab.) Print all graphs for your TA to sign, and for your future reference.

- 2 The carts used in this activity have two kinds of ends. One set of ends allows the carts to stick together (interlocking velcro tape), while the other set of ends, equipped with strong magnets, causes the carts to repel each other.

Before performing the lab, you need to check that the frictionless track is level.

**CAUTION:**  
The space between the photogates should be wide enough that the collision happens after the first cart completely passes the first photogate. **Before each collision**, place the second cart right in front of the second photogate. The first cart has to be launched from left to right in the positive  $x$ -axis direction.

**Important:** The first photogate must be connected to channel 1 in the interface to activate the system after cart 1 passes it.

- 3 To measure the velocities of the carts, apply “Linear Fit” to the position-time graphs produced after each run. A sample graph is shown in Fig. 4. Because the track and the carts are not totally frictionless, it is recommended to fit only a small part of the recorded position, closest to the instant of collision. In other words, linear fit should be applied to the last 3–5 points for cart 1 (top graph) and to the first 3–5 points for cart 2 (bottom graph). This will provide the initial velocity of cart 1 right before the collision, and velocity after the collision for cart 2. The graphs will have a different view depending on the collision.

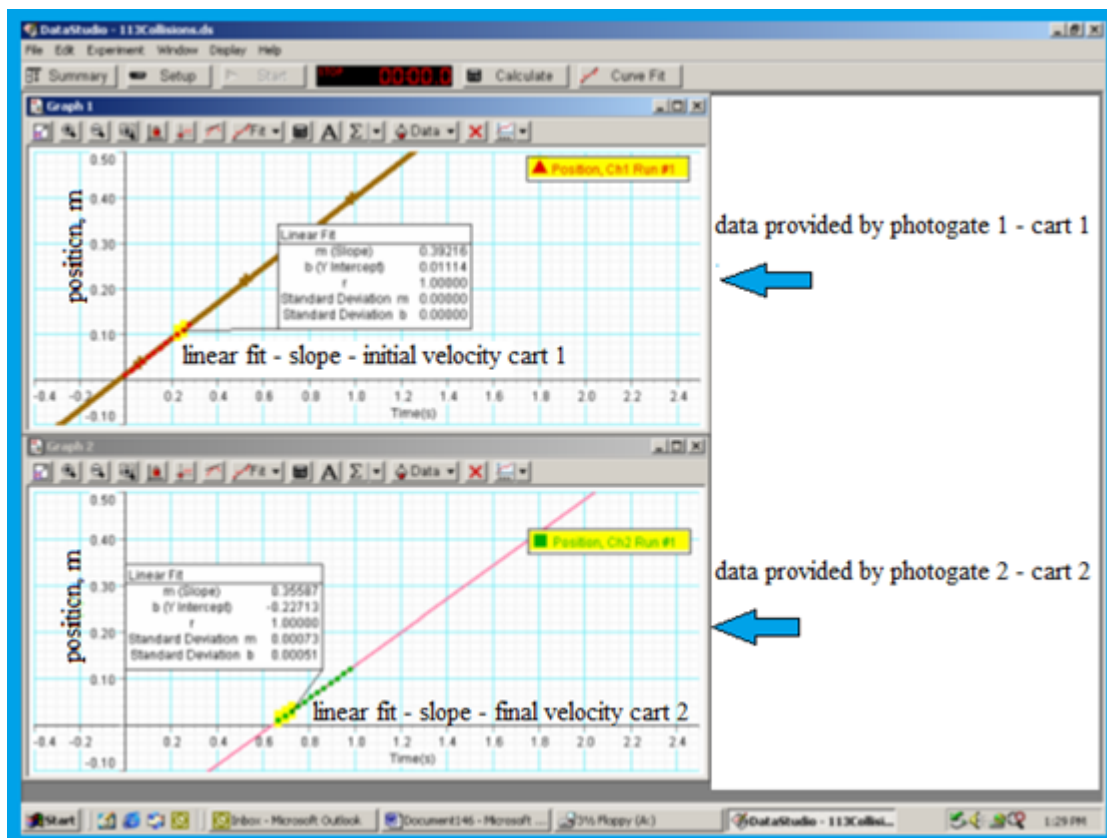


Figure 4: A sample of the experiment file in Data Studio

- 4 On the lab worksheet, make a sketch of the first, inelastic collision (carts stick together after the collision), where  $m_1 = m_2$  and  $\mathbf{v}_{2i} = 0$ . Make the required prediction. Note that when the carts stick together and move together after the collision, the velocity of both carts is the same.

Perform the experiment. Complete the corresponding column in Table 1 in the Inlab. Take a screenshot of your graphs with linear fit data to upload in the Inlab.

- 5 On the lab worksheet, make a sketch of the second, inelastic collision (carts stick together after the collision), where  $m_1$  does not equal  $m_2$  and  $\mathbf{v}_{2i} = 0$ . Make the required prediction. Note that when the carts stick together and move together after the collision, the velocity of both carts is the same.

Perform the experiment. Complete the corresponding column in Table 1 in the Inlab. Take a screenshot of your graphs with linear fit data to upload in the Inlab.

- 6 On the lab worksheet, make a sketch of the third, elastic collision (carts stay separated after the collision), where  $m_1 = m_2$  and  $\mathbf{v}_{2i} = 0$ . What happened to the first cart after the collision?

Perform the experiment. Complete the corresponding column in Table 1 in the Inlab. Take a screenshot of your graphs with linear fit data to upload in the Inlab.

- 7 On the lab worksheet, make a sketch of the fourth, elastic collision (carts stay separated after the collision), where  $m_1$  is less than  $m_2$ . To significantly change the mass of the cart, add the heavy metal block.

Perform the experiment. Complete the corresponding column in Table 1 in the Inlab. Take a screenshot of your graphs with linear fit data to upload in the Inlab.

- 8 Follow the directions in the Show My Work section of the lab worksheet. Complete the further calculations based on the data reported in Table 1 to make a conclusion about whether the momentum was conserved in all types of collisions and whether kinetic energy was conserved in all types of collisions.