

## Collisions In One Dimension

## Lab 11

Equipment SWS, meter stick, 2 photogates, air track, 2 gliders of same mass, 1 glider of different mass, 2 cards for top of gliders to interrupt photogate beam, 4 paper clips, 2 disk magnets, 2 pieces of velcro 2 in. long

## 1 Purpose

To investigate conservation of energy and momentum in one dimensional 2 body collisions.

## 2 Theory

### 2.1 Conservation of Momentum

Let the mass of a particle be  $m$  and its velocity  $\vec{v}$ . The momentum  $\vec{p}$  is defined by  $\vec{p} = m\vec{v}$  and Newton's 2nd law may be written as  $\vec{F} = \frac{d}{dt}\vec{p}$  where  $\vec{F}$  is the net force on  $m$ . If  $\vec{F} = 0$  this yields  $\vec{p} = \text{constant}$  which is Newton's 1st law.

For a system of particles we identify each particle with a subscript  $i$  so that  $\vec{F}_i = \frac{d}{dt}\vec{p}_i$ . If each side of this equation is summed over all the particles

$$\sum_{i=1}^n \vec{F}_i = \vec{F} = \frac{d}{dt} \sum_{i=1}^n \vec{p}_i = \frac{d}{dt} \vec{P},$$

where  $n$  is the number of particles,  $\vec{F}$  is the net force on the system, and  $\vec{P}$  is defined as the momentum (or the total momentum) of the system. In the sum over  $\vec{F}_i$  the internal forces (the forces between the particles) can be excluded as Newton's 3rd Law guarantees that they will cancel out. We don't even have to know them. A consequence of this equation is that if any component of  $\vec{F} = 0$  that component of  $\vec{P}$  will be a constant. This will be true even if some of the particles make violent collisions with each other as collisions produce only internal forces. One can say that the component of momentum is the same before the collisions as it is after the collisions, or that the component of momentum is conserved. If all components of  $\vec{F} = 0$  then all components of the momentum are conserved.

Conservation of energy and conservation of momentum are different statements. Momentum may be conserved when energy is not.

### 2.2 Definitions

In this lab we restrict ourselves to two body collisions. A collision is said to be elastic if the combined KE of the two objects is the same before the collision as after the collision. If the KE is less after the collision the collision is called inelastic. If the two objects stick together the collision is called completely or perfectly inelastic. In this last case maximum KE is lost.

### 2.3 Two Particle One Dimensional Collisions

Elastic collisions. The 2 particles will be gliders on a horizontal air track and we will only be concerned with the motion along the air track. Vector notation is not needed. The gliders will be referred to by subscripts 1 and 2. Unprimed quantities will refer to time before the collision and primed quantities to times after the collisions. Before the collision particle 2

will be at rest. The direction of motion for particle 1 before the collision will be taken as positive. Let  $m$  stand for mass and  $v$  for velocity. For elastic collisions conservation of energy and momentum give

$$\frac{1}{2}m_1v_1^2 = \frac{1}{2}m_1v_1'^2 + \frac{1}{2}m_2v_2'^2, \quad \text{and} \quad m_1v_1 = m_1v_1' + m_2v_2'.$$

The quantity  $v_1$  is assumed known. These equations can be solved (very easily if you are clever!) for  $v_1'$  and  $v_2'$  to give

$$v_1' = \frac{m_1 - m_2}{m_1 + m_2}v_1, \quad \text{and} \quad v_2' = \frac{2m_1}{m_1 + m_2}v_1.$$

For what circumstances does the incident glider reverse its direction during the collision?

Perfectly inelastic collisions. Energy is not conserved. The gliders stick together during the collision and  $v_1' = v_2'$ . Momentum conservation gives  $m_1v_1 = (m_1 + m_2)v_1'$ . This equation gives

$$v_1' = v_2' = \frac{m_1}{m_1 + m_2}v_1.$$

### 3 Collision Experiments

#### 3.1 Description

One glider is at rest on the horizontal air track. Another glider, whose mass may larger, smaller, or the same, strikes the glider at rest. Two photogates measure the velocities of the gliders before and after the collision.

#### 3.2 Photogate Setup

Cards inserted in the top of the gliders will serve to interrupt the photogate beams. The cards can be moved along the top of the gliders. To minimize the effects of friction arrange the photogates and cards so that the velocities are measured as close to the collision point as feasible. For elastic collisions one of the photogates will measure 2 velocities.

#### 3.3 Programming

Program SWS twice for photogate sensor & opaque object. For each photogate enter the width of the card on top of the glider. Open the table display window by dragging its icon to one of the photogate icons, choosing velocity. Click the add column button and open up another column for the other photogate, again choosing velocity.

#### 3.4 Elastic Collisions

The spring bumpers on the gliders are fairly but not completely elastic. If two small disk magnets are available, these can be mounted in the appropriate orientation on the bumpers for repulsion. Take data for  $m_1 = m_2$ ,  $m_1 < m_2$ , and  $m_1 > m_2$ . Try a few velocities for  $m_1$ . Compare your data to the equations for elastic collisions. How well is energy conserved? Do your results differ from the theory in the way you might expect if a bit of KE is lost in the collision?

An elastic collision is defined as a collision where the KE of the objects is the same before and after the collision. Is the KE the same during the collision? If not, where does the energy go during the collision? Explain for the case of spring bumpers and magnet bumpers.

### 3.5 Perfectly Inelastic Collisions

To make the 2 gliders stick together during the collision use 4 paper clips to attach 2 in. pieces of velcro to one bumper of each glider. Use the same combinations of masses as in the previous section and analyze your data in the same way, using the equation for a perfectly inelastic collision. Verify that KE is lost. Where does the energy go?

## 4 Comment

When using the concepts of momentum and energy be aware that waves carry both of these quantities. When the gliders collide do you hear a sound? Could this contribute to the energy and momentum balance in your experimnts. Probably not. For example the sound from a “quiet conversation” has a sound intensity of about  $10^{-6} W/m^2$ . If it is assumed that this level of sound is produced by the ocllision for .1 s at a distance of 1 m from the collision, and that the sound radiates isotropically from the collision point, the total energy in the sound wave would be  $1.3 \times 10^{-6} J$ . How does this compare with the kinetic energy of your gliders?