

## CONSERVATION OF MOMENTUM AND ENERGY (AIR TRACK)

### PREPARATORY QUESTIONS

1. Make sure that you understand the principle of conservation of momentum. When two carts collide, is momentum conserved at each instant before, during and after the collision? If the carts are of equal mass what happens to their individual momenta during and after the collision? What about the case in which one cart is twice as massive as the other? Also consider the case in which the two carts stick together after the collision.
2. Review your understanding of the conservation of kinetic energy. What is the difference between elastic and inelastic collisions? When two carts collide, what would you expect will happen to the total kinetic energy during and after the collision? Consider the cases in which the carts a) bounce apart and b) stick together after the collision.
3. Consider an elastic collision between two masses  $m_1$  and  $m_2$  with initial velocities  $v_{1i}$  and  $v_{2i}$ . From conservation of momentum, express  $v_{2f}$ , the final velocity of  $m_2$  in terms of  $m_1$ ,  $m_2$ ,  $v_{1i}$ ,  $v_{2i}$  and  $v_{1f}$ .
4. Consider an inelastic collision between two masses  $m_1$  and  $m_2$  with initial velocities  $v_{1i}$  and  $v_{2i}$ . From conservation of momentum, express  $v_f$ , the final velocity of the combined mass in terms of  $m_1$ ,  $m_2$ ,  $v_{1i}$ , and  $v_{2i}$ .
5. The web site:  
<http://faraday.physics.utoronto.ca/PVB/Harrison/Flash/ClassMechanics/AirTrack/AirTrack.html> has an animation showing elastic and inelastic collisions. Use the formulae from questions 3 and 4 to determine if the final velocities in these animations are correct or not.

### THE EXPERIMENT

**Note:** although it is not strictly necessary, your data will be easier to analyze if you start off with a level track. *Question:* what will be the difference in your data if the track is NOT level? First check that the two stops are fixed to the central portion of the track, about 1 m or so apart. The across-track leveling (at right angles to its length) is not critical, so it is sufficient to use the supplied spirit level and the two leveling screws at one end. Once you have leveled in this direction, **both** of the leveling screws must be given the **same** number of turns in all further adjustments.

Leveling the air track along its length is much more critical. Switch on the air blower, and place a cart on the track. Use the leveling screws to reduce the movement of the cart. If the track is level, the cart should stay in place over an extended period. Occasionally you may find that a track is bent in some way; at these places the cart will tend to move to a local minimum; remember that it is an “average” level between the two stops that you require.

Gather sufficiently good data on several “hard” collisions (with bumpers), and “sticky” collisions (using Velcro to join the carts after collision). In at least one of the collisions, use carts of differing mass. Several suggestions follow.

#### Notes & Hints

- Use two motion sensors facing each other along the track. Set the triggering rate to its maximum value (25 per second when two Motion Sensors are in use). For this rate the distance between the two Motion Sensors should not be much more than about 1.5 m.
- Make sure the Motion Sensors are switched to the “narrow beam” option.
- Don’t collide the carts at too high speeds or they may jump slightly off the air track thus introducing added complexity.

- Ensure that the two carts are moving at quite different speeds before the collision.
- A total of 4 or so good sets of data - two each of elastic and inelastic, with equal and unequal mass carts - are probably sufficient.
- Make sure you keep track of the experimental conditions of each, run such as which sensor monitors which cart, in your notebook.

Now use DataStudio to make plots of the total momentum of the carts before, during and after the collision (you will also need to know the masses of the carts you used). The following suggestions may be useful as you analyze each data run in turn.

1. Display the position of Channels 1&2 and 3&4 for the run under consideration.
2. Display the velocity of Channels 1&2 and 3&4 for the same run.
3. Highlight the velocity for either Channels 1&2 or Channels 3&4 by clicking on the appropriate graph and then click on the calculator icon on the graph toolbar.
4. Create a formula for the total momentum of the carts (remember that you will need to change the sign of one of the velocities - why?). The prompts will ask you to define any variables in this formula. Each mass variable is a *Constant* and each velocity variable is a *Data Measurement* whose *Data Source* is the appropriately labeled *Velocity* run.
5. The formula will appear in the list in the *Data* window. The graph in which the *Data* for the formula appears is determined by the units of the *Y* variable. The units may be arbitrarily changed by clicking on *Properties* in the *Calculator* window and changing the *Y Variable* units in the *Data Properties* window.
6. Now follow a similar set of steps for the total kinetic energy of each collision.
7. Remember to make notes in your notebook of your observations; you may want to print out some - not all!! - of your graphs for later discussion.
8. Save the file.

Using the  $\Sigma$  pull-down menu on the graph toolbar, you can obtain various statistics for any data you select; you will need means and standard deviations. Using this feature on the momentum and kinetic energy graphs that you have made, give careful answers to the following questions.

What does your data tell you about momentum and kinetic energy before, during and after the collisions? Since this is real life data, there are uncertainties in each measured quantity. How do you know that the variations caused by these uncertainties are not indicators of true deviations from constancy? Or, to put it another way, if you observe a deviation from a “constant” value, is this real, or only a reflection of the uncertainties in your data? These questions are of course, fundamental in any experimental investigation, and can be answered only using knowledge of statistical analysis. For an explanation of Standard Deviation and Standard Error see the web page on error analysis

(<http://www.upscale.utoronto.ca/PVB/Harrison/ErrorAnalysis/index.html>).

For the elastic collision with unequal masses, measure  $v_{1i}$ ,  $v_{2i}$ ,  $v_{1f}$  and  $v_{2f}$ . From conservation of momentum, taking  $v_{1i}$ ,  $v_{2i}$  and  $v_{1f}$  as known, calculate  $v_{2f}$  and compare your result to the measured value. For the inelastic collision with unequal masses, measure  $v_{1i}$ ,  $v_{2i}$  and  $v_f$ . Taking  $v_{1i}$  and  $v_{2i}$  as known, calculate  $v_f$  and compare your result to the measured value.