

Laboratory 11: Conservation of Momentum – Activity

The law of conservation of momentum states that for a system of objects on which there is *no net external force*, the total momentum remains constant. The aim of this laboratory is to investigate this for collisions between two carts as illustrated in Fig. 1.

The momentum of any single cart at a given instant is

$$\vec{p} = m\vec{v}$$

where m is the mass of the cart and \vec{v} is the velocity of the cart at the instant. The total momentum of the system at any instant is $\vec{p}_{\text{total}} = \vec{p}_A + \vec{p}_B$ where \vec{p}_A is the momentum of cart A at that instant and \vec{p}_B is the momentum of cart B at the same instant. Conservation of momentum implies that $\vec{p}_{\text{total before}} = \vec{p}_{\text{total after}}$. This laboratory exercise aims to verify this fact.

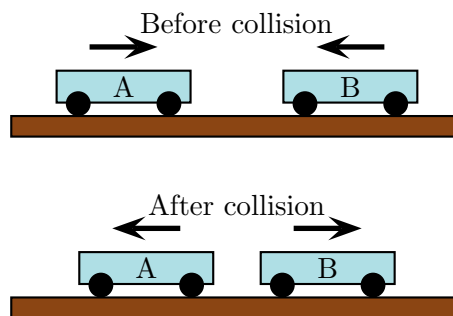


Figure 1: Colliding carts

1 Experimental Set Up

The experiment uses a track and two PASCO collision carts. The speeds with which the carts move before and after the collision and be determined via a pair of photogates.

- A short video that illustrates the equipment and the collisions is available to you at a location specified by the instructor. The three types of collisions are: an *elastic collision* in which the carts approach and bounce off each other, and *inelastic collision* in which the carts stick together and an *explosion* in which the carts are initially both at rest and then fly apart. View the video and verify that it shows three distinct types of collisions.
- In each collision there is a blue cart and a silver cart. For each cart in each collision, describe whether the cart's momentum is positive, negative or zero before the collision according to what the video shows. Repeat this for after the collision.

The experiment was run by the instructor several times for each type of collision and the data will be given to you.

2 Elastic Collision

In an elastic collision the carts approach each other, collide and rebound as illustrated in Fig 2. This was done with carts of unequal masses oriented so as to allow built in magnets to repel during the collision. The masses of the carts and their speeds before and after the collisions were recorded.

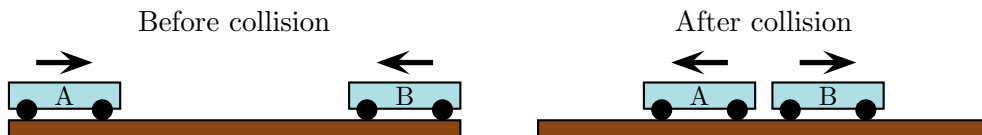


Figure 2: Elastic collision

- For each collision, calculate the horizontal (or x) component of the total momentum before and after the collision. Does the momentum appear to be conserved?
- Let Δp_{total} be the difference between the total momentum after the collision and the total momentum before the collision. Determine Δp_{total} for each collision. What does the theory predict that it should be?
- Determine the best estimate and uncertainty of Δp_{total} for all of the elastic collisions (instructions for doing this are given on page 6). The range of statistically plausible outcomes for Δp_{total} is the set of all numbers from $\overline{\Delta p_{\text{total}}} - \text{uncertainty}$ to $\overline{\Delta p_{\text{total}}} + \text{uncertainty}$. Determine the range of plausible outcomes for Δp_{total} for this experiment.
- The experiment will show that momentum is conserved if the theoretically expected value of Δp_{total} lies within the range of outcomes provided by the experiment. Does the experiment show that momentum is conserved? If not, is it close to doing so?

3 Inelastic Collision

In an inelastic collision involves carts that adhere as illustrated in Fig 3. The carts are equipped with velcro tabs that allow them to adhere and the experiment was run so that this occurred. Several such collisions were performed and the speeds of the carts before and after the collision were recorded.

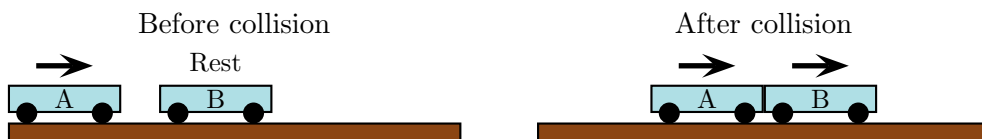


Figure 3: Inelastic collision

- For each collision, calculate the horizontal (or x) component of the total momentum before and after the collision. Does the momentum appear to be conserved?
- Let Δp_{total} be the difference between the total momentum after the collision and the total momentum before the collision. Determine Δp_{total} for each collision. What does the theory predict that it should be?
- Determine the range of plausible outcomes for Δp_{total} for the set of these collisions. Use this to verify whether the experiment shows that momentum is conserved. If not, is it close to doing so?

4 Explosion

In an “explosion” both carts are held at rest against each other. One of the carts is equipped with a plunger that pushes the carts apart after it is triggered. This is illustrated in Fig 4. Several such explosions were performed and the speeds of the carts before and after were recorded.

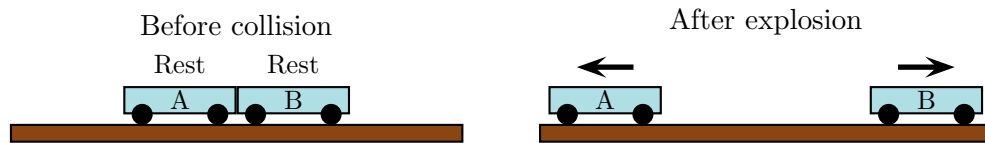


Figure 4: “Explosion”

- For each explosion, calculate the horizontal (or x) component of the total momentum before and after the explosion. Does the momentum appear to be conserved?
- Let Δp_{total} be the difference between the total momentum after the explosion and the total momentum before the explosion. Determine Δp_{total} for each explosion. What does the theory predict that it should be?
- Determine the range of plausible outcomes for Δp_{total} for the set of these explosions. Use this to verify whether the experiment shows that momentum is conserved. If not, is it close to doing so?

5 Conclusion

- What do these experiments establish?
- Explain any discrepancies between your observations and the theoretical predictions. For your explanation you should consider:
 - How accurately you were able to measure the quantities needed to carry out the calculations.
 - Whether there were any “external” forces present that were excluded from the analysis.

6 Best Estimate and Uncertainty in an Experiment

Any experiment will, if repeated, yield fluctuating outcomes. Typically these outcomes will all lie within a small range. We need to extract a representative outcome from all of these and quantify the extent of the fluctuations. The subject of Error Analysis provides a framework for doing this that is rooted in probability theory and statistics.

Suppose that the experiment is done N times and gives outcomes; $x_1, x_2, x_3, \dots, x_N$. The *best estimate* for these is the mean,

$$\bar{x} := \frac{x_1 + x_2 + x_3 + \dots + x_N}{N} \quad (1)$$

and this represents the outcome of the experiment.

The spread of the outcomes is calculated in a two-stage process. First the *standard deviation* of the measurement outcomes measures the extent to which they are scattered and is defined as

$$\sigma := \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \bar{x})^2}. \quad (2)$$

There are techniques that simplify computing this. Scientific calculators and software such as Excel can take a list of the outcomes and automatically return the standard deviation (in Excel this is `stdev(...)`). The *uncertainty* in the experimental result is the *standard deviation of the mean (STDOM)*, defined as

$$\delta x := \frac{\sigma}{\sqrt{N}}. \quad (3)$$

The experimental result is then expressed as

$$\bar{x} \pm \delta x. \quad (4)$$

The number of significant figures in the uncertainty, δx , should be one and the best estimate, \bar{x} should be terminated at the same decimal point as the uncertainty.

Setting up the photogate timer

Separately connect each Photogate in the interface icon. This will produce a Timer icon in the Tools palette. Click on the Timer icon and do as follows:

- ① Select Pre-configured and click next.
- ② Select Photogate Ch. 1 and click Photogate Ch. 2.
- ③ Select Collision (Single Flag) and click next.
- ④ Check the speed in gate 1 box and speed in gate 2 boxes and click next.
- ⑤ Use the default parameters and click next.
- ⑥ Provide a name and click next.
- ⑦ Click finish.