Conservation of Momentum

Purpose

To verify the conservation of momentum in one dimension.

Introduction and Theory

Momentum, $\boldsymbol{p}$, is a vector quantity. It is defined as the product of the mass and velocity of a body:

$$\mathbf{p} = m\,\mathbf{v}$$

The total momentum of a system, consisting of multiple bodies, is the sum of the individual momenta of each body.

In this experiment, two carts starting from rest are pushed away from each other without external forces (an "explosion"). The total initial momentum of the system is zero. Conservation of momentum predicts that the final momentum of the system must also be zero, so:

$$\mathbf{p}_{\text{final}} = \mathbf{p}_1 + \mathbf{p}_2 = m_1\mathbf{v}_1 + m_2\mathbf{v}_2 = 0$$

Because the two carts are traveling in opposite direction, this is equivalent to

$$m_1 v_1 - m_2 v_2 = 0 \quad \text{or} \quad m_1 v_1 = m_2 v_2$$

In other words, the momenta of the two carts after the explosion should be equal and opposite. That is what we are trying to verify today.

Note that the masses and speeds of the two carts may be different, but the magnitude of the product of their mass and speed – momenta – should be equal. We are going to test this for three cases:

Case 1: two carts have equal masses;
Case 2: one cart has about 0.5 kg more mass than the other;
Case 3: one cart has about 1.0 kg more mass than the other.

Assuming constant velocity motion, we measure the speeds of the carts v_1 and v_2 by "distance over time". We will manage to start and stop the two carts at the same time, so that the time intervals are the same for the two carts.

Apparatus

Draw a labelled diagram of the apparatus (add to Figure 1 as needed) and list all other apparatus needed, along with any identifying numbers.

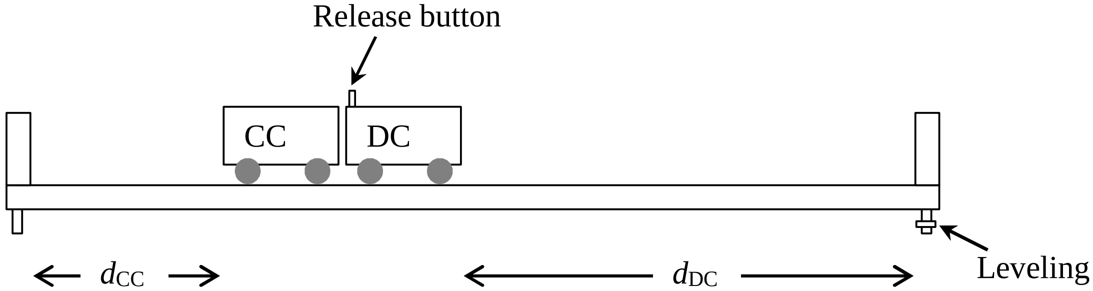

Figure 1

Data

1. Level the track by adjusting the levelling screw. The spirit levels are at the front desk. Return the level when you are done.

2. Measure the masses of each cart and each mass bar, one at a time. Record the results in a table, identifying them by their labels. The zero reading of the 2-pan balance should be zero so no corrected reading is needed. Half of the smallest division of the 2-pan balance is 0.05g. The uncertainty also depends on how many counter-masses you use. For each counter-mass, add another 0.05g to the uncertainty.

3. Compress the spring loaded plunger on Cart DC and lock it in place. Place both carts end to end on the track. Tap the release button lightly with a short stick. This is our “explosion”. If you are successful, the two carts should be pushed away quickly.

4. Try to make the two carts reach the ends at the same time. This can be done by observing which cart hits the end first and adjusting the starting position accordingly. You should hear only one “BANG” when the carts hit the ends of the track.

5. When you find the best starting position, you are ready to measure the speeds of the two carts. Use the stopwatch to measure the time interval. To find the speeds of the carts, the distances traveled by each cart must also be recorded.

6. Measure the time intervals and the distances traveled for each case:

   Case 1: both carts are empty;
   Case 2: cart CC is loaded with mass bar A, cart DC is empty;
   Case 3: cart CC is loaded with mass bars A and B, cart DC is empty.

   For each case, your data table should include the time interval (common for both carts), the starting positions of each cart, the ending positions of each cart, and the distance traveled by each cart. Add another row to record the uncertainty for each quantity.

7. To find the uncertainty in the time intervals, see how fast you can turn on and off the stopwatch. This should give you a good idea of how many significant digits the time intervals have.

Calculations

Prepare another table in this section: for each of the three cases, list the total mass of each cart (including any mass bars), the speed of each cart, and the momentum (magnitude only) of each cart. Below the table, show *all* your calculations. All numbers in the Calculations section should be kept to 5 digits.

Note that your report will end up with 4 tables: one for the mass data, one for the position/distance and time data, one for the calculation results (above) and one for the conclusions (below).

Conclusions

Summarize your results in a table like the following. Fill in the appropriate units in the brackets. Express the results to the appropriate number of significant digits!

Table 1: comparing the magnitudes of momenta of the two cars after the "explosion"

	Momentum of the cart CC p_{CC} (unit:)	Momentum of the cart DC p_{DC} ( )	Difference $\lvert p_{CC} - p_{DC} \rvert$ ( )	$\frac{\lvert p_{CC} - p_{DC} \rvert}{(p_{CC} + p_{DC})/2} \times 100\%$
Case 1				
Case 2				
Case 3				

Discussion

The last column of the table is to see if the percentage difference of the momenta of the two carts is zero. Due to uncertainty in the measured data, this will not be exactly zero. Nonetheless, we can still say the resulting difference agrees with zero if the percentage difference is "small". Answer the following questions:

1. If the momenta of the two carts after the "explosion" are equal in magnitude, why can we say that momentum is conserved? (Hint: what would be the momentum of the system after the "explosion", and would it be equal to the momentum before?)

2. Based on your percentage discrepancies, does your momentum appear to be conserved for each of the three cases? Why do you say so?

3. What *physical* reasons can lead to momentum of the system not being conserved? Use reasons other than "human error" and "data uncertainties".