Conservation of Momentum

NAME: ____________________

Day: _____ **Time:** _______ Partner: ________________

Momentum: An object with mass m and velocity $\vec{v}$ has momentum $\vec{p}$ equal to

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

If a system has several objects, the momentum is the sum of all the momentum vectors. So, if there are two objects with momenta $\vec{p}_1$ and $\vec{p}_2$, the momentum of the system is

$$\vec{p}_{\text{total}} = \vec{p}_1 + \vec{p}_2 .$$

In this lab, we will consider the momentum of a system of two cars on a track. This is a one-dimensional system, so the vector notation will be dropped. The signs of the velocity and momentum indicate their directions: + to the right, - to the left. This is important -- you must get the signs right!

Conservation of momentum:

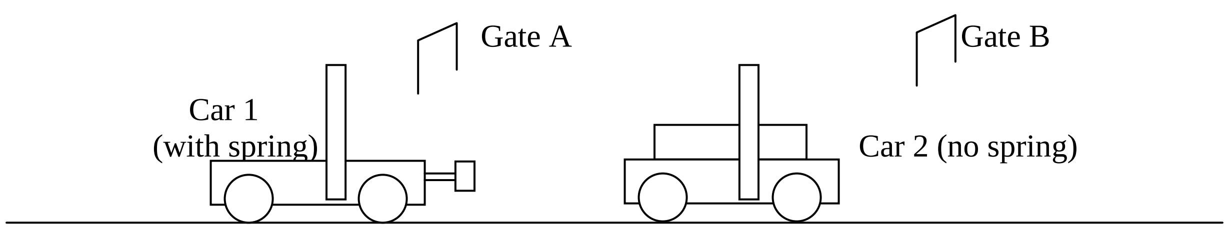
A fundamental law of physics says: **momentum is conserved in all processes**, provided the total external force is zero. This means the momentum of our two-car system should stay unchanged, even if the cars collide, fly apart, or bounce off each other.
We will test this experimentally. To do so, we must minimize all unwanted external forces.

Examples of external forces to try and eliminate are:

i. frictional forces retarding the cart (hence remove dust from the track and make sure the wheels are turning smoothly);
ii. gravitational force (hence ensure the track is completely horizontal)

The velocity measurements will be done with a pair of photo-gates. The operation of this system (choose elastic collision mode, four decimal places, two memories) will be explained in the lab. The speed of a car is found from the time its flag is in the gate, and the carefully measured width of the flag.

General setup:



Measurements for all parts of this lab:

	Mass (kg)	Flag width (m)
Car 1		
Car 2		

Experiment 1: Car 1collides with stationary car 2

Load Car 2 with a single 500-g bar and place it stationary between the gates. Start Car 1 from a position to the left of gate A with spring released and facing Car 2. This situation is illustrated above. Push Car 1 towards car 2, releasing it *before* it enters gate A. Give it enough speed to bounce back through gate A and to send Car 2 through gate B.

Before collision			**After collision**		
Car 1	Mass (kg)		Car 1	Mass (kg)	
	Time A1 (seconds)			Time A2 (seconds)	
	Velocity (m/s)			Velocity (m/s)	
	Momentum (kg·m/s)			Momentum (kg·m/s)	
Car 2	Momentum (for zero velocity)		Car 2	Mass (kg)	
				Time B1 (s)	
				Velocity (m/s)	
				Momentum (kg·m/s)	
Total momentum (kg·m/s)			Total momentum (kg·m/s)		

Find the percentage difference in the two momenta. Show the numbers used in the calculation.

$$\%\text{diff} = \left| \frac{p(\text{before}) - p(\text{after})}{p(\text{before})} \right| \times 100$$

% diff = ________________

Experiment 2: Car 1 and Car 2 stick together after the collision
The setup is as for the previous experiment, but this time the Car 1 spring is retracted to allow the Velcro strips to hold the cars together. **Note**: Press clear before each new run.

Before collision			**After collision**		
Car 1	Mass (kg)		Double car	Mass (kg)	
	Time A1 (seconds)			Time B1 (seconds)	
	Velocity (m/s)			Velocity (m/s) **	
	Momentum (kg·m/s)			Momentum (kg·m/s)	
Car 2	Momentum (for zero velocity)				
Total momentum (kg·m/s)			Total momentum (kg·m/s)		

Use conservation of momentum to *calculate* the theoretically predicted final velocity (see **) of the double car after the collision. Use the measured masses of the two cars and the velocity you found for Car 1 before the collision.
Instructions: Include a diagram of the cars before and after contact, with the symbols you plan to use in the equations. Express the conservation equation using your chosen symbols, and only use numbers at the last step. When done get your instructor's initials in the box.

Calculate the percentage difference in the tabulated momenta (last line of table) before and after the collision. Show the numbers used in your calculation.

% diff =________________________

Experiment 3: Cars flying apart

Place both cars motionless between the gates. They should be almost touching so that the spring on Car 1, initially retracted, will strike Car 2 when released. Use the bottom of the mass holder (or another solid, flat surface) to tap the release pin on Car 1. The cars should move in opposite directions through the gates. Repeat for the four possible ways the carts can be loaded with either zero or one mass bars.

What is the initial momentum? ________________________

After break-up of cars		No loads	Car 1 loaded	Car 2 loaded	Both loaded
Car 1	Mass (kg)				
	Time A1 (s)				
	Velocity (m/s)				
	Momentum (kg·m/s)				
Car 2	Mass (kg)				
	Time B1 (s)				
	Velocity (m/s)				
	Momentum (kg·m/s)				
Total momentum after break-up (kg·m/s)					

For the case where both cars are unloaded ('No loads'), calculate the theoretically predicted velocity of Car 2 after the break-up assuming conservation of momentum. Use the measured masses of the two cars, and the velocity found for Car 1.

Experiment 4: Both cars launched towards each other.
Start Car 1 to the left of gate A and start Car 2 to the right of gate B. The spring on Car 1 must be extended towards Car 2. Launch the cars towards each other to collide between the gates and then move back out through the gates. Be sure to release the cars before they enter the gates. Practice a few times to get the right launch speeds. You should get good results if the cars move fast enough to not slow down noticeably.

Before collision				**After collision**			
		Both unloaded	Car 2 loaded (500 g)			Both unloaded	Car 2 loaded (500 g)
Car 1	Mass (kg)			Car 1	Mass (kg)		
	Time A1 (seconds)				Time A2 (seconds)		
	Velocity (m/s)				Velocity (m/s)		
	Momentum (kg·m/s)				Momentum (kg·m/s)		
Car 2	Mass (kg)			Car 2	Mass (kg)		
	Time B1 (s)				Time B2 (s)		
	Velocity (m/s)				Velocity (m/s)		
	Momentum (kg·m/s)				Momentum (kg·m/s)		
Momentum--both unloaded (kg·m/s)				Momentum--both unloaded (kg·m/s)			
Momentum--Car 2 loaded (kg·m/s)				Momentum--Car 2 loaded (kg·m/s)			

Find the difference in the momenta as a percentage of the initial momentum of Car 1:

$$\%\text{diff} = \left|\frac{p(\text{before}) - p(\text{after})}{p(\text{Car1})}\right| \times 100 .$$

Show the calculation, with the numbers used:

% diff (unloaded)=___________ % diff(Car 2 loaded)=_____________

Experiment 5: Kinetic energy loss in collisions (or not)

Collisions can be classified according to whether or not the total kinetic energy remains constant ("is conserved").

Elastic collision: KE (after) = KE (before)

Inelastic collision: KE (after) < KE (before)

Collisions between atoms and molecules are usually elastic. For cars such as ours, there is always a reduction in the kinetic energy during the collision.

Find the percentage loss of kinetic energy in Experiments 1 and 2.

<table>
<tr><th colspan="2"></th><th>KE before (J)</th><th>KE after (J)</th><th>% diff</th></tr>
<tr><td rowspan="3">Expt 1</td><td>KE car 1</td><td></td><td></td><td rowspan="3"></td></tr>
<tr><td>KE car 2</td><td></td><td></td></tr>
<tr><td>KE total</td><td></td><td></td></tr>
<tr><td rowspan="3">Expt 2</td><td>KE car 1</td><td></td><td rowspan="3">Combined cars</td><td rowspan="3"></td></tr>
<tr><td>KE car 2</td><td></td></tr>
<tr><td>KE total</td><td></td></tr>
</table>

Note: Calculate the percentage difference using

$$\%\,\text{diff in KE} = \frac{KE(\text{before}) - KE(\text{after})}{KE(\text{before})} \times 100$$