# Young Physicists Program: November 2010
# Lab 2: Energy and Momentum- Can't stop us now!

## Laboratory: Showing conservation of energy and momentum

**Introduction**
The purpose of this lab is to become familiar with the ideas of **conservation of energy** and **conservation of momentum**. Take some time to discuss: What is momentum? What quantities do you need to measure momentum? What has more momentum- a basketball or a train? Or does it depend on their respective speeds? What is energy? Can you give an example of it? How is energy related to doing "work"? Which has direction? Can both be negative? What does it mean to be conserved? Work these into the labs as you go.

**Conservation of Mechanical Energy and Projectiles**
You have a curved ramp with the bottom at the edge of the desk and you start with a ball at rest at the top. The end of the ramp is horizontal. When the car leaves the ramp, it falls to the floor on a **ballistic** trajectory. The horizontal distance, between the end of the ramp and where the car hits the floor, is called the range.

When the ball is at the top of the ramp it has some potential energy that depends on the height it is being released from. When you release the ball the potential energy is converted into kinetic energy that gives the ball speed. Conservation of energy tells us that $E_i = E_f$ .

$$PE = mgh$$
$$KE = \frac{1}{2}mv^2$$

What quantities do you think may be important for finding the range of the car? Discuss which ones are important and which ones are not.

Measure the quantities necessary to predict the range. Record these measurements in your notebook. Calculate what the range of your car will be using the equation:

$$X = 2\sqrt{Hh}$$

where H is the height from the top of the track to the bottom of the track, and h is height from the bottom of the track to the floor.

Practice releasing the car from the top of the track. Make sure the car remains in contact with the track until it reaches the end. Note qualitatively the outcome. Without measuring, does it look like the car lands in the same place each time?

Release the car from the top of the ramp and measure the range of the car. Record your measurement in a table. Repeat the experiment a few times to get the average and spread of experimental values.

| Trial | H (cm) | h (cm) | $X = 2\sqrt{Hh}$ (cm) | Measured range (cm) |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |

How does your measured range compared to the predicted range X? Are there any peculiarities that you notice (during the trial or in the data) that might suggest that the data are unreliable? How does the measured value compare to the calculated value?

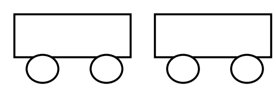
**Mechanical Energy and Friction (optional for advanced students)**
As the cart comes down the ramp, it loses energy to friction. This energy is transformed to heat, sound and maybe other forms of energy. If we can measure the mechanical energy lost to friction we can use that value to predict the expected range for different initial heights of the car. (If you are an advanced student you may want to try this if there is extra time.)

$$PE = KE + W_{friction}$$

**Conservation of Momentum**
When two objects separate and no net external force act on the system, linear momentum is conserved. Applying this principle, if the two objects start at rest, the final momentum of the objects must be equal and opposite.

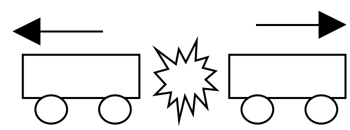
***Initial***

$$m_1 v_1 = 0; m_2 v_2 = 0 \Rightarrow P_i = 0$$



***Final***

$$m_1 v_1 - m_2 v_2 = 0 \Rightarrow P_f = 0$$



From this final state we can infer a relationship between the ratio of the masses and the ratio of the velocities.

$$m_1 v_1 = m_2 v_2 \Rightarrow \frac{m_2}{m_1} = \frac{v_1}{v_2}$$

To further simplify the calculations, the carts will be placed so that they will reach the end of the track simultaneously (Δt will be the same for both carts).

$$\frac{v_1}{v_2} = \frac{\frac{\Delta x_1}{\Delta t}}{\frac{\Delta x_2}{\Delta t}} = \frac{\Delta x_1}{\Delta x_2}$$

Finally, it can be inferred that the ratio of the masses is equal to the ratio of the distances:

$$\frac{\Delta x_1}{\Delta x_2} = \frac{m_2}{m_1}$$

***Procedure:***

1. Level the track so that a cart will not roll when placed at rest on the track.
2. Take the dynamics cart and push the spring released mechanism completely in until it latches in its maximum position. Place the two carts against each other on the track so that the mechanism is between them.
3. Next, release the spring by pressing squarely with a pencil or something along those lines on the trigger located on the top of the cart so that the two carts travel to the ends of the track. Experiment with starting positions until they reach the ends at the same time.
4. When you find the correct starting position, weigh the two carts on a beam balance; record the masses and the starting position in the table below.
5. Finally, calculate the distances traveled by each cart ($x_1$ & $x_2$). Then fill in the two final columns $x_1/x_2$ and $m_1/m_2$ .

Do this for four cases:

- both carts without any weights
- a weight in one cart, none in the other
- two weights in one cart, none in the other
- two weights in one cart, one in the other

| mass 1 (kg) | mass 2 (kg) | Starting position (cm) | $x_1$(cm) | $x_2$(cm) | $x_1/x_2$ | $m_1/m_2$ |
| --- | --- | --- | --- | --- | --- | --- |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |

Does the ratio of the distances equal the ratio of the masses in each of the cases; hence, is momentum conserved?

If not, what are possible source of error for the experiment?

What factors have we ignored that might come into effect here?

# Demonstrations: Putting energy and momentum conservation to use: rockets and cannons and racers!

**Newton’s Cradle**
Here you will show the students Newton’s Cradle. Where does momentum conservation come in? Where does energy conservation come in? Are both needed?

**Racing marbles on tracks**
Use the two wooden tracks provided as a demonstration. Both tracks start and end at the same heights but follow different paths from these two points. Before releasing marbles from the top of the tracks, ask the students which path will have a marble reach the end first- will both reach the end at the same time? What will the velocity of the two marbles be at the end of the tracks? Will the marbles travel the same distance when they fly off the end of the tracks, which are horizontal in both cases? Then release the marbles and let the students continue to debate!

**Galilean Cannon**
Now we head outside for a few demonstrations. The Galilean Cannon is similar to Newton's Cradle in that it requires both conservation of energy and momentum to explain the phenomena of the cannon. Before dropping the stack of bouncy balls, ask the students what they think will happen. Will the entire apparatus bounce up to approximately its previous height? If not, how many bouncy balls will fly off and how far into the air will they fly, compared to how high we dropped it from? Then let this thing drop and ask the students why we have such a spectacular launching of the smallest ball. *Note: don't drop the cannon from too high a height, or we will likely lose the smallest ball.*

**Mentos-propelled rocket**
Here we show momentum conservation in a very explicit way: after dropping mentos-like candy into a two liter bottle of a highly carbonated drink attached to a cart on a track, the liquid ejected out of the back of the cart moves the cart forward because of conservation of momentum. A cart has already been designed to handle this reaction, though the result will be messy!

**Methanol-propelled rocket**
This is a similar example to the candy-propelled rocket, but more powerful and louder. We use a 2-liter bottle attached to a string and use a modified cap as a nozzle to expel the methanol when combusted. Have two students hold either end of a string. Make sure the student behind the ignition point is at least ten feet away. A graduate student who is comfortable with the task will use a propane mini-torch to light the methanol in the bottle and propel the rocket. Assign one student to time how long it takes for the rocket to come from start to stop. Assign two-three students to measure the total distance the rocket traveled. From this, calculate the average velocity of the rocket. Then measure the mass of the bottle (we will approximate the mass in the kinetic energy as the mass of the bottle without the methanol fuel). Calculate the kinetic energy of the rocket as it traveled. One gram of methanol releases 22,000 J of energy during a combustion reaction. Assuming we used one gram of methanol to propel the rocket, how does this compare to the kinetic energy of the rocket we measured? Why would there be any differences?