

Linear momentum and One-dimensional Collisions

Purpose

1. Study Linear momentum and its conservation.
2. Study different types of collisions and discern whether kinetic energy is conserved or not.

Introduction

Linear momentum of an object is defined as the product of the mass of the object and its velocity:

$$\mathbf{P} = m\mathbf{v} \quad (1)$$

Since the velocity is a vector, so is the linear momentum, a vector (it has the direction of the velocity).

Impulse is defined in physics as:

$$\mathbf{F}\Delta t \quad (2)$$

where, F is the force and Δt is the time during which the force is applied. By Newton's second law: $\mathbf{F}_{net} = \frac{d\mathbf{p}}{dt}$, the force is equal to the time rate of change of linear momentum, we can conclude that the impulse is equal to the change in linear momentum:

$$\mathbf{F}\Delta t = \Delta\mathbf{p} \quad (3)$$

Consider figure 1. If two block are allowed to collide on a frictionless track, the only forces are the internal forces of the blocks on each other, \mathbf{F}_1 of block 1 on block 2 and \mathbf{F}_2 of block 2 on block 1. By Newton's third law these two forces are action reaction forces. So

$$\mathbf{F}_1 = -\mathbf{F}_2 \quad (4).$$

The two forces are equal and opposite in direction. If we multiply eqn. 4 by Δt , the time of impact and using equation 3, we get:

$$\Delta\mathbf{p}_1 = -\Delta\mathbf{p}_2 \quad (5)$$

where, Δp_1 is the change in momentum of m_1 and Δp_2 is the change in momentum for m_2 .

We can write eqn. 5 as:

$$m_1 v_{1f} - m_1 v_{1o} = -(m_2 v_{2f} - m_2 v_{2o})$$

and rearranging we get:

$$m_1 v_{1o} + m_2 v_{2o} = m_1 v_{1f} + m_2 v_{2f} \quad (6)$$

We can read equation 6 as: linear momentum before collision equals linear momentum after collision. This is the law of conservation of linear momentum. It applies to any system where the net external forces on the system equal zero.

If an object is moving with a speed v , it has a certain form of energy called 'kinetic energy', KE . The kinetic energy depends on the mass of the object and its speed. It is defined as

$$KE = \frac{1}{2}mv^2 \quad (7)$$



Figure 1: Collision of two blocks on a frictionless track

Since the kinetic energy is a form of energy, then it has the unit of energy, the 'Joule', J .

We will study three types of collision:

- a) Totally inelastic collision: where the two objects stick together after the collision. The linear momentum is conserved but the kinetic energy is not conserved.
- b) Perfectly elastic collision: where the objects do not touch each other in the collision (they can be repelled by magnets), so no energy is lost in sound or deformation. The linear momentum is conserved and also the kinetic energy is conserved.
- c) Inelastic collision: where the linear momentum is conserved but the kinetic energy is not conserved. This represents most of the actual collisions.

Running the experiment

The data sheet is on pages 3 and 4

Part 1: Totally inelastic collision

- 1) Consider figure 1. If the mass of m_1 is 5 kg and its initial velocity, v_{10} is 10 m/s , the mass of m_2 is 3 kg , and its initial velocity, v_{20} is -8 m/s (the negative is for the left direction). Calculate the initial linear momentum and initial kinetic energy before collision. Show your calculation and record in the data sheet.
- 2) Open the simulator <http://ophysics.com/e2.html> click and drag the elasticity to set the elasticity to zero. This means that the collision of the blocks will be totally inelastic and the blocks will stick together after collision.
- 3) Click Run. Pause the simulator after the collision occurs. Notice the graphs of velocity and linear momentum. Record the velocities of the blocks after the collision as given by the simulator.
- 4) Calculate the final linear momentum and the final kinetic energy after the collision. Compare initial and final linear momentum. Is the linear momentum conserved? Compare the initial and final Kinetic energy. Is the kinetic energy conserved? Compare your calculated values for final momentum and final kinetic energy with those measured by the simulator.

Part 2: Perfectly elastic collision

- 1) Set the elasticity to 1. This will cause the collision to be perfectly elastic. In the actual lab this can be nearly achieved by using repelling magnets on the side of the carts where they collide.

Click Reset. Notice the initial velocities did not change from their values of part 1. So the initial linear momentum and kinetic energies are the same as those of part one. Copy them to the data sheet.

- 2) Repeat steps 3 and 4 of part 1.

Part 3: Inelastic collision

- 1) Set the elasticity to 0.4. Click Reset. Again the initial values are the same. So copy the initial linear momentum and kinetic energy that you calculated in part 1.

- 2) Repeat steps 3 and 4 of part 1.

Questions

1. What are the differences in your experimental results between the perfectly elastic and inelastic collisions?
2. If the masses of the carts are equal in the elastic collision, what should happen to the blocks after the collision?

3. When a truck and a car are traveling with same speed make a head-on collision, is the force exerted by the car on the truck equal, greater or lesser than that exerted by the truck on the car?
4. Explain, using linear momentum, why a rifle must recoil in the opposite direction of the bullet when fired?
5. Verify that the units of 'Impulse' and 'Change in momentum' are essentially same.

Data sheet

Name:

Group:

Date experiment performed:

Part 1: Totally inelastic collision

Step 1) Calculation of initial linear momentum (show your work):

Calculation of initial kinetic energy (show your work):

Step 3) $v_{1f} =$ m/s $v_{2f} =$ m/s

Step 4) Calculation of final linear momentum (show your work):

Calculation of final kinetic energy (show your work):

How do your calculated values compare to those measured and displayed by the simulator?.....

Is the linear momentum conserved?

Is the kinetic energy conserved?

Part 2: Perfectly elastic collision

Step 1) Initial linear momentum:

Initial kinetic energy:

Step 2) $v_{1f} =$ m/s $v_{2f} =$ m/s

Calculation of final linear momentum (show your work):

Calculation of final kinetic energy (show your work):

How do your calculated values compare to those measured and displayed by the simulator?.....

Is the linear momentum conserved?

Is the kinetic energy conserved?

continue to the next page

Part 3: Inelastic collision

Elasticity = 0.4

Step 1) Initial linear momentum:

Initial kinetic energy:

Step 2) $v_{1f} =$ m/s $v_{2f} =$ m/s

Calculation of final linear momentum (show your work):

Calculation of final kinetic energy (show your work):

How do your calculated values compare to those measured and displayed by the simulator?.....

Is the linear momentum conserved?

Is the kinetic energy conserved?

Answers to questions:

1.

2.

3.

4.

5.