Collisions

1 Introduction

This quarter, we've learned about how to calculate the speed and distances that objects move at and to. But what happens when they hit each other? Two concepts, known as *Kinetic Energy* and *Momentum*, help us to understand what happens in a collision.

2 Kinetic Energy

Kinetic energy is the energy possessed by moving objects. We can represent it through the equation:

$$KE = \frac{1}{2}mv^2 \tag{1}$$

Where m is the mass of the object, and v is its velocity. We represent kinetic energy as Joules (J), where $1J = 1\frac{kg \cdot m^2}{s^2}$. As a result, heavier and faster objects will have a higher kinetic energy.

Problem 1 *Marcus is practicing throwing baseballs. If the ball has a mass of 0.25 kg and Marcus throws it at 25 m/s, what is the kinetic energy of the ball?*

Problem 2 *Tanish is moving chess pieces through 5-D hyperspace at a speed of* $4m/s$*. If his rook has a kinetic energy of* $1J$*, how much does it weigh?*

Question 1 *Does a large object moving at a slow speed or a small object moving at a fast speed have more kinetic energy?*

3 Momentum

Momentum represents how much an object is able to push other objects. We can represent it through the equation:

$$p = mv \tag{2}$$

Where m *is the mass of the object and* v *is the speed of the object. Note that* v *can also be represented as a vector.*

Question 2 *Does a large object moving at a slow speed or a small object moving at a fast speed have more momentum?*

Problem 3 *Seth is go-karting with his friends. If the combined weight of him and his kart is 150 kg, and he is driving at 2 m/s, what is his momentum?*

The momentum of a system of objects is the same as the sum of the individual momentums. This can be represented by the equation:

$$p_{total} = \Sigma p = m_1 v_1 + m_2 v_2 + ... \tag{3}$$

In other words, the total momentum is the sum of each of the masses times their velocities. The Law of Conservation of Momentum states that the total momentum of a system always stays the same, unless an external force is applied. As a result, p_{total} will always stay the same.

Example 1 *Tanish and Marcus are playing basketball on a frozen court. Tanish passes a basketball weighing 0.5 kg to Marcus at a speed of $5m/s$. If Marcus weighs 60 kg, what velocity does he travel at after catching the ball?*

The momentum of the ball can be calculated as:

$$p_{ball} = mv = 0.5kg \cdot 5m/s = 2.5kg \cdot m/s$$

Marcus' momentum is

$$p_{marcus} = mv = 60kg \cdot 0m/s = 0$$

Therefore, their combined momentum is:

$$p_{total} = p_{ball} + p_{marcus} = 2.5kg \cdot m/s$$

To get their combined velocity, we divide their momentum by their combined mass:

$$v = \frac{p_{total}}{m_{total}} = \frac{2.5kg \cdot m/s}{60kg + 0.5kg} = 0.04m/s$$

Problem 4 *Seth forgot to wear his seat belt, and hits the edge of the track. Assuming that Seth weighs 60 kg and the kart stops completely, how fast does Seth fly out of the kart?*

Problem 5 *What is Seth's kinetic energy as he flies out of the kart?*

4 Impulse

Momentum allows us to calculate the speed and weight of colliding objects, but not the force applied onto them.

Impulse allows us to calculate these forces. Impulse is the change in momentum for an object, and can be represented by:

$$J = p_{final} - p_{initial} \tag{4}$$

Note: This J means impulse, not Joules.

Impulse can also be used to calculate the force experienced by an object:

$$F = \frac{J}{\Delta t} = \frac{p_{final} - p_{initial}}{\Delta t} = \frac{mv_f - mv_i}{t_f - t_i} \tag{5}$$

Question 3 *Why does falling onto a trampoline not hurt you?*

Problem 6 *After flying out of the car, Seth hits a pile of tires. What is the impulse that Seth experiences?*

Problem 7 *The tires cushion Seth's fall, and cause him to stop over 2 seconds. What is the force that Seth experiences?*

Problem 8 *It takes 4,000 N of force to break a bone. Is Seth okay?*

5 Challenge Problems

Problem 9 *Sofia is playing pool, and hits a 112 g ball at 1.5 m/s. The ball hits a second ball of the same mass moving in the opposite direction at 0.5 m/s. The second billiard ball rebounds and travels at 0.5 m/s after the head-on collision. What is the velocity of the first ball after the collision?*

Problem 10 *Sofia is practicing rolling bowling balls, and rolls a 5 kg bowling ball at a 5 m/s. Tanish accidentally drops a tennis ball, and it rolls into the bowling ball at a 90 degree angle. The tennis ball has a mass of 0.05 kg and is rolling at a speed of 1 m/s. The chalk dust on the floor of the classroom sticks the bowling ball and tennis ball together. What is the velocity of this new object?*
Hint: Separate the X and Y-velocities and use the Pythagorean Theorem to calculate the final velocity.