12.4
Momentum and Impulse

Momentum

Let's assume there's a car speeding toward you, out of control without its brakes, at a speed of 27 m/s (60 mph). Can you stop it by standing in front of it and holding out your hand? Why not?

Unless you're Superman, you probably don't want to try stopping a moving car by holding out your hand. It's too big, and it's moving way too fast. Attempting such a feat would result in a number of physics demonstrations upon your body, all of which would hurt.

Momentum

We can't stop the car because it has too much momentum. Momentum is a vector quantity, given the symbol “p”, which measures how hard it is to stop a moving object. Of course, larger objects have more momentum than smaller objects, and faster objects have more momentum than slower objects.

Momentum

Momentum can be defined as "mass in motion." All objects have mass; so if an object is moving, then it has momentum.

Momentum depends upon 2 variables:

1. Mass
2. Velocity

Momentum

Formula:

Momentum = mass x velocity

$p = m \cdot v$

p = momentum (kg•m/s)
m = mass (kg)
v = velocity (m/s)

Momentum is a vector

- Momentum is a vector, so the direction of momentum is the same as the direction of the velocity vector.
- An object's momentum will change if its mass and/or velocity (speed and direction) changes.

Momentum is a vector

- According to Newton’s laws, a net force causes an object to accelerate, or change its velocity.
- A net force, therefore, causes a change in an object’s momentum.

Momentum

Question:

Two trains, Big Red and Little Blue, have the same velocity. Big Red, however, has twice the mass of Little Blue. Compare their momentum.

Answer:

Because Big Red has twice the mass of Little Blue, and Big Red must have twice the momentum of Little Blue.

Momentum Example #1

Example #1

A supersonic bomber, with a mass of 21,000 kg, departs from its home airbase with a velocity of 400 m/s due east. What is the jet's momentum?

$p = m \cdot v$

$p = 21{,}000 \text{ kg} \cdot 400 \text{ m/s east}$

$p = 8{,}400{,}000 \text{ kg m/s east}$

Momentum Example #2

Example #2

Now, let's assume the jet drops its payload and has burned up most of its fuel as it continues its journey to its destination air field.

If the jet's new mass is 16,000 kg, and due to its reduced weight the pilot increases the cruising speed to 550 m/s, what is the jet's new momentum?

$p = m \cdot v$

$p = 16{,}000 \text{ kg} \times 550 \text{ m/s east}$

$p = 8{,}800{,}000 \text{ kg m/s east}$

Momentum Example

Example #3

A 588 N halfback is moving eastward at 9 m/s. What is their momentum?

539.45 kg m/s east

Momentum Example

Example #4

What is the momentum of a 1,000 kg car moving northward at 20 m/s.

20,000 kg·m/s north

Impulse

If momentum changes, its because mass or velocity change.

Most often mass doesn't change so velocity changes and this is acceleration.

And then we get:

p = mass x Δv (Don't forget Δ is "change in")

p = mass x Acceleration

p = force

Impulse

Applying a force over a time interval to an object changes the momentum. A change in momentum is known as an impulse.

The vector quantity for impulse is represented by the letter "J", and since it's a change in momentum, its units can be one the same as those for momentum, [kg·m/s], and can also be written as a Newton-second [N·s].

Note: In sports, impulse is called the "follow through"

Impulse

<u>Impulse Formula:</u>

Impulse = force x time

Impulse = Δp

$J = F \cdot t$ (N·s)

$J = \Delta p = (p_f - p_i)$ (kg·m/s)

J = Impulse

p = momentum (kg·m/s)

F = force (N)

t = time (s)

Impulse Example #1

Let's assume the bomber from the previous problem, which had a momentum of 8,800,000 kg·m/s east, comes to a halt on the ground. What impulse is applied?

$J = \Delta p = (p_f - p_i)$

p = 0 - 8,800,000 kg•m/s east

p = - 8,800,000 kg m/s east

p = 8,800,000 kg m/s west

Impulse Example #2

If the football halfback experienced a force of 800 N for 0.9 seconds to the north, determine the impulse.

$J = F \cdot t$
$J = 800N\ (\ 0.9s\ )$
$J = 720\ N{\cdot}s$

Impulse Example #3

A 0.10 Kg model rocket's engine is designed to deliver an impulse of 6.0 N·s. If the rocket engine burns for 0.75 s, what is the average force does the engine produce?

$J = F \cdot t$

$6.0\ N \cdot s = F\ (\ 0.75s\ )$

$6.0\ N \cdot s\ /\ 0.75\ s = F$

$8.0\ N = F$

Impulse-Momentum Theorem

Since momentum is equal to mass times velocity, we can write that.

We also know that impulse is a change in momentum, so impulse can be written as $J = \Delta p$. If we combine these equations, we find:

$P = mv$

$J = \Delta p$

$J = \Delta p = \Delta(mv)$

Impulse-Momentum Theorem

Since the mass of a single object is constant, a change in the product of mass and velocity is equivalent to the product of mass and change in velocity. Specifically:

$J = \Delta p = m\Delta v$

So we're talking about changes in velocity... but what do we call changes in velocity? Of course, acceleration! And what causes acceleration? A force! And does it matter if the force is applied for a very short time or a very long time? Absolutely it does.

Impulse-Momentum Theorem

Common sense tells us the longer the force is applied, the longer the object will accelerate, the greater the object's change in momentum!

Let's apply Newton's Second Law to what we know:

$F = ma$

$F = m(\Delta v/\Delta t)$

$F = (m\Delta v)/(\Delta t)$

Rearranging: $F\Delta t = m\Delta v$

Impulse-Momentum Theorem

$F\Delta t = m\Delta v$

$J = F\Delta t$

$\Delta P = m\Delta v$

Therefore we can say that:

$J = \Delta P$

$m\Delta v = F\Delta t$

Impulse-Momentum Theorem

$m\Delta v = F\Delta t$

This equation relates impulse to change in momentum to force applied over a time interval.

To summarize: When an unbalanced force acts on an object for a period of time, a change in momentum is produced, known as an impulse.

This is the Impulse-Momentum Theorem

Impulse-Momentum Example #1

A tow-truck applies a force of 2,000 N on a 2,000 kg car for a period of 3 seconds. What is the magnitude of the change in the car's momentum?

$\Delta p = F\Delta t$

$\Delta p = (2{,}000\ N)\ (3\ s)$

$\Delta p = 6{,}000\ N\cdot s$

Impulse-Momentum Example #2

A tow-truck applies a force of 2,000 N on a 2,000 kg car for a period of 3 seconds. What is the magnitude of the change in the car's momentum? ***If the car starts at rest, what will be its speed after 3s?***

$\Delta p = 6{,}000\ N\cdot s$

$\Delta p = (p_f - p_i) = mv_f - mv_i$

$6{,}000\ N\cdot s = 2{,}000 \cdot v_f - 2{,}000 \cdot 0$

$V_f = 3\ m/s$

Impulse-Momentum Example #3

An impulse of 11 Ns from a rocket engine has 12.5 g of fuel. What is the exhaust velocity?

$m\Delta v = F\Delta t$

$(.0125\ \text{kg})\ (v_f - v_i) = 11\ \text{Ns}$

$v_f = 880\ \text{m/s}$

Impulse-Momentum Example #4

A Bullet traveling at 500 m/s is brought to rest by an impulse of 50 Ns. What is the mass of the bullet?

$m\Delta v = F\Delta t$

m (500 m/s – 0 m/s)= 50 Ns

m = (50 Ns) / (500 m/s)

m = .1 kg

Impulse-Momentum Example #5

While waiting in a car at a stoplight, an 80 kg man and his car are suddenly accelerated to a speed of 5 m/s as the result of a rear end collision. Assuming the time taken to be 0.3 s, find:

a. The momentum of the man
b. The force exerted on him by the back of the seat of the car.

$p = m \cdot v$
$p = 80\text{ kg} \cdot 5\text{ m/s}$
$p = 400\text{ kg}\cdot\text{m/s}$

$m\Delta v = F\Delta t$
$400\text{ kg*m/s} = F \cdot 0.3\text{ s}$
$F = 1{,}333.33\text{ N}$