Module 8: Impulse and Momentum

Impulse & Momentum

OBJECTIVES:

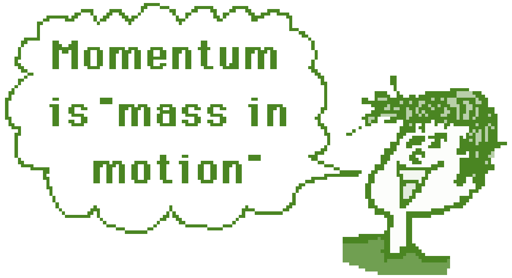
1. Define and relate Impulse and Momentum
2. Explain the Law of Conservation of Momentum
3. Differentiate the two main types of collision
4. Solve problems involving impulse and momentum

Momentum

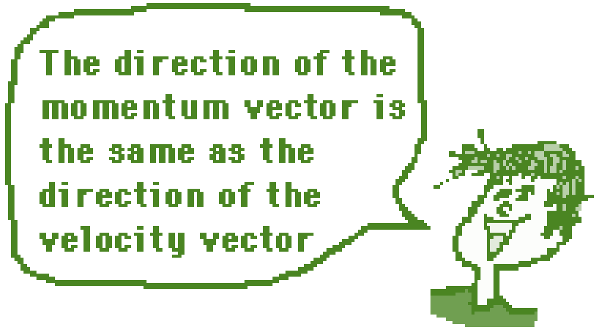
- Momentum is a quantity that describes an object's resistance to stopping (a kind of "moving inertia").
- It is represented by the symbol p (boldface) with a unit of kilogram-meter per second.
- It is the product of an object's mass and velocity.
- It is a vector quantity (since velocity is a vector and mass is a scalar).

$$p = mv$$

https://www.physicsclassroom.com/class/momentum



https://www.physicsclassroom.com/class/momentum



https://www.physicsclassroom.com/class/momentum

https://www.physicsclassroom.com/class/momentum

$$p \propto m$$

The **larger the mass** moving the same speed the **larger the momentum.**

The 5 kg car going 10 m/s:

- p=mv
- p=(5)(10) = 50 kg·m/s of momentum

The 35 kg car going 10 m/s:

- p=mv
- p=(35)(10) = 350 kg·m/s of momentum

$$p = mv$$

10 m/s

least momentum

10 m/s

10 m/s

most momentum

Momentum

p ∝ v

The 15 kg car going 0 m/s:

- p=mv
- p=(15)(0) = 0 kg·m/s of momentum

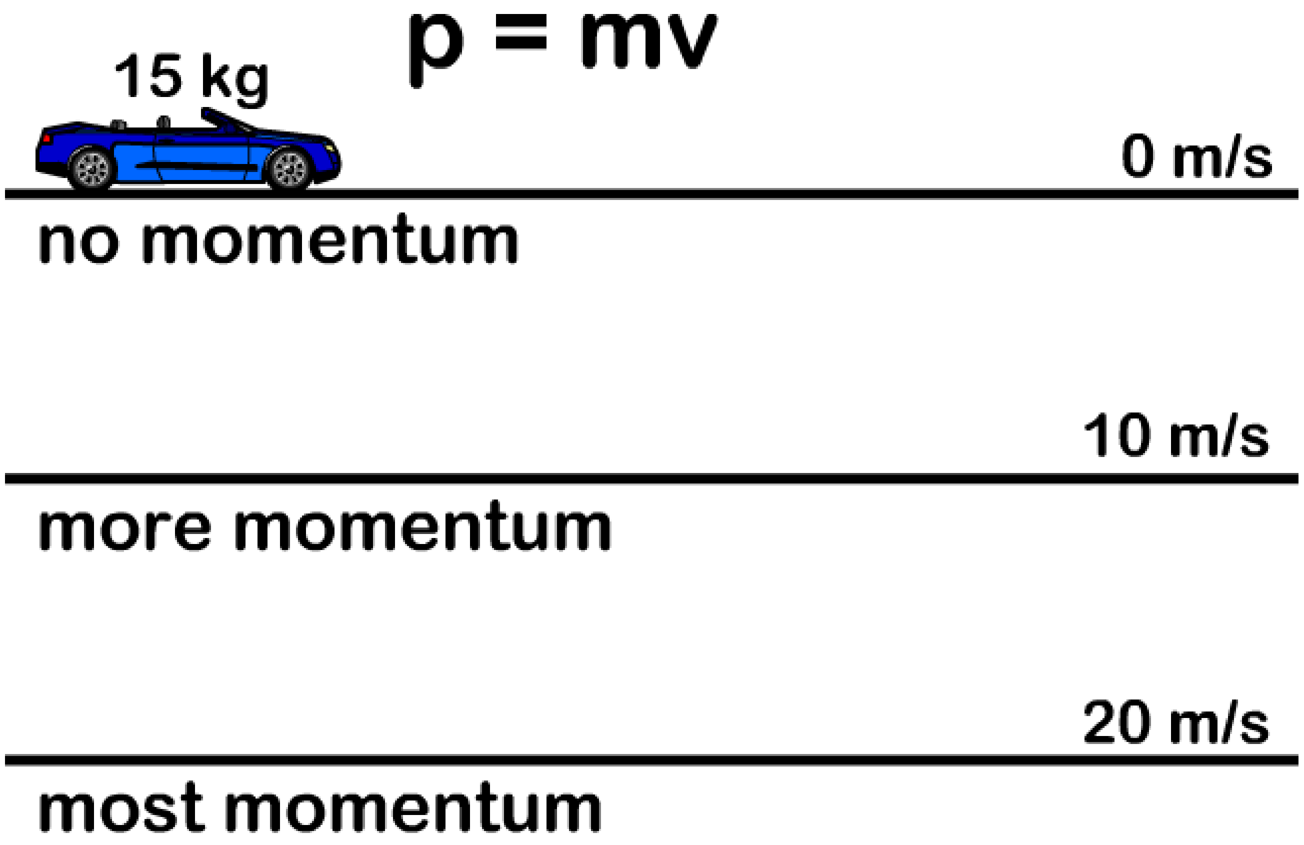
The 15 kg car going 10 m/s:

- p=mv
- p=(15)(10) = 150 kg·m/s of momentum

The 15 kg car going 20 m/s:

- p=mv
- p=(15)(20) = 300 kg·m/s of momentum

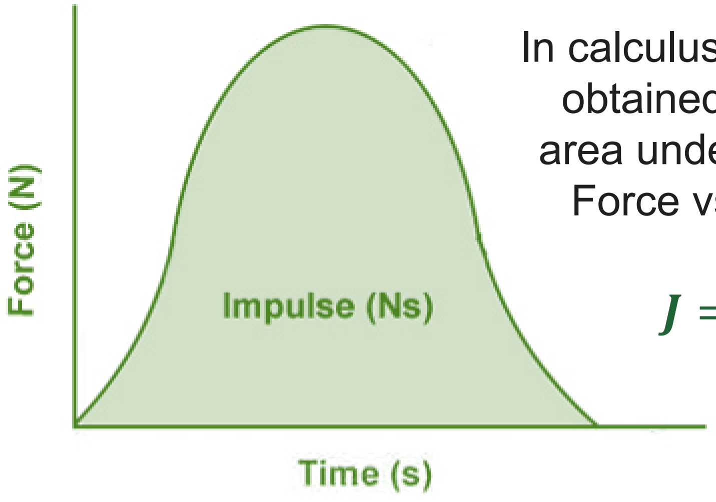
The same car going double the speed has double the momentum.



Impulse

- It is a vector quantity that describes the effect of a net force acting on an object (a kind of "moving force").
- Impulse is represented by the symbol J (boldface) with a unit of Newton-second.
- It is mathematically defined as the product of the average net force acting on an object and its duration.

$$J = F\Delta t$$

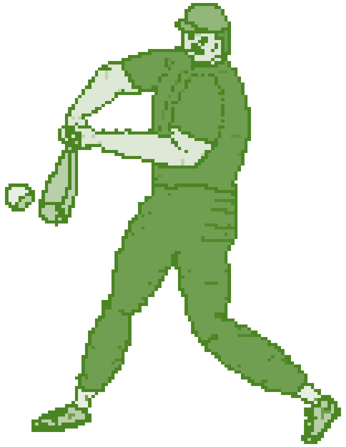


https://www.physicsclassroom.com/class/momentum

In calculus, Impulse can be obtained by getting the area under the curve of a Force vs. Time graph.

$$\boldsymbol{J} = \int F\,dt$$

A real life example would be a baseball player hitting a ball in different amount of time.



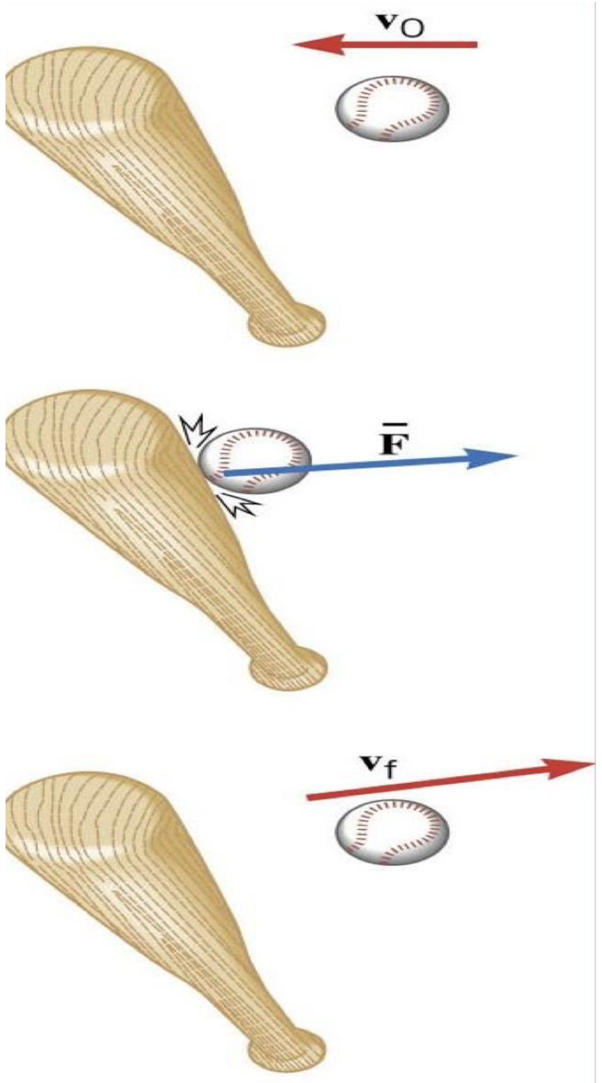
https://www.physicsclassroom.com/class/momentum

http://epiphanyvideoworks.com/Science/Hughes/Units/Work&MachinesContent.htm

Impulse

- IMPLUSE is required to change the momentum of an object.
- A net force acting for some time will cause an object to change its momentum.
- Impulse=change in momentum
- We assume that the net force is constant throughout the duration of changing momentum. (Usually use average net force.)
- An **impulse (J)** is a force applied for a time, which results in a change of momentum.

A bat creates an impulse when force is applied for a time period changing a baseballs momentum.



Impulse from Momentum

From Newton's second law:

$$\boldsymbol{F = ma}$$

We combined it with the definition of acceleration (a = change in velocity / time), the following equalities result:

$$\boldsymbol{F = m\frac{\Delta v}{t}}$$

And since momentum is $force\ times\ time$, we change the left-hand side of the equation to:

$$\boldsymbol{F * t = m\frac{\Delta v}{t}}$$

Therefore, $\boldsymbol{J = m\Delta v = p}$

$$\boldsymbol{J = m\Delta v = p}$$

Impulse = Change in momentum

Impulse-Momentum Theorem

The impulse-momentum theorem states that the change in momentum of an object equals the impulse applied to it.

$$J = \Delta p$$

If mass is constant, then…

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

If mass is changing, then…

$$F\,dt = m\,dv + v\,dm \text{ (calculus based)}$$

The impulse-momentum theorem is logically equivalent to <u>Newton's second law</u> of motion (the force law).

Impulse-Momentum Theorem

Two crucial concepts in the impulse-momentum theorem:

1. Impulse is a vector quantity

$$-(10\ \mathrm{N} \cdot \mathrm{s}) \neq +(10\ \mathrm{N} \cdot \mathrm{s})$$

2. An impulse does not cause momentum; rather, it causes a <u>change</u> in the momentum of an object. Thus, you must subtract the final momentum from the initial momentum

Example

A 0.145-kg baseball is moving at 35 m/s when it is caught by a player.

a) Find the change in momentum of the ball.

b) If the ball is caught with the mitt held in a stationary position so that the ball stops in 0.050 s, what is the average force exerted on the ball?

c) If, instead, the mitt is moving backward so that the ball takes 0.500 s to stop, what is the average force exerted by the mitt on the ball?

Example

A 50.0 kg object is moving at 18.2 m/s when a 200 N force is applied opposite the direction of the object's motion, causing it to slow down to 12.6 m/s. How long was this force applied?

Example

A 1,000 kg car is moving at 20 m/s when it crashes into a wall. The driver is wearing a seatbelt, and the airbag deploys, stopping the car in 0.8 seconds.

a) What is the impulse experienced by the car?

b) What force does the airbag exert on the car?

Conservation of Momentum and Collisions

Action: Reaction
same force
$\mathbf{F}_1 = -\mathbf{F}_2$

but: $m_1 \neq m_2$
so: $\mathbf{a}_1 \neq \mathbf{a}_2$

with: $m_1 \neq m_2$
then: $\Delta\mathbf{v}_1 \neq \Delta\mathbf{v}_2$

though:
$m\Delta\mathbf{v}_1 = m\Delta\mathbf{v}_2$

$\Delta\mathbf{p}_1 = \Delta\mathbf{p}_2$

Conservation of Momentum
$\mathbf{p}_1 + \mathbf{p}_2 = \text{constant}$

Conservation of Momentum

"When no net force acts on a system, the total momentum remains constant in magnitude and direction."

$$\boxed{\mathbf{p}_1 + \mathbf{p}_2 = \text{constant}}$$

Note:

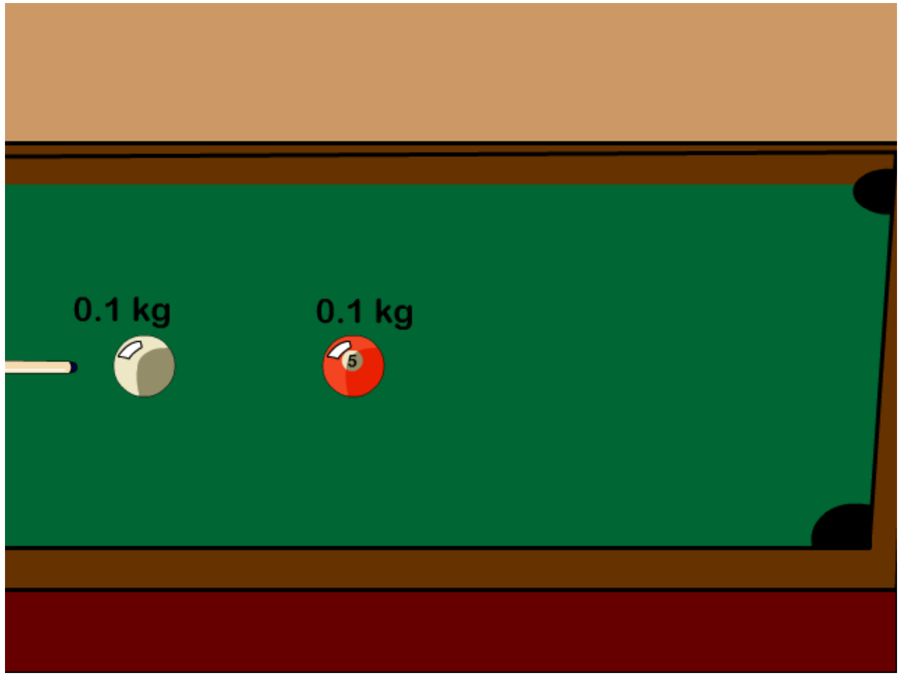
Rightward direction is (+)

Leftward direction is (−)

conservation of momentum in any collision, including elastic collisionselastic collision	$m_1\mathbf{v}_1 + m_2\mathbf{v}_2 = m_1\mathbf{v'}_1 + m_2\mathbf{v'}_2,$
conservation of momentum in a perfectly inelastic collision	$m_1\mathbf{v}_1 + m_2\mathbf{v}_2 = (m_1 + m_2)\,\mathbf{v}'$

Conservation of Momentum

- Momentum can be transferred from one object to another and shared between multiple object remaining in contact.
- Conservation of momentum can be used to calculate the effects on a baseball player and baseball when thrown.
- Elastic collisions occur when two objects collide but maintain their form.
- Inelastic collisions include scenarios where two objects travel together.



Collision between two objects

$$J = \Delta P$$

$$J = p_{initial} - p_{final}$$

$$J = (m_1 v_{i1} + m_2 v_{i2}) - (m_1 v_{f1} + m_2 v_{f2})$$

$$0 = (m_1 v_{i1} + m_2 v_{i2}) - (m_1 v_{f1} + m_2 v_{f2})$$

$$\boldsymbol{(m_1 v_{i1} + m_2 vi_2) = (m_1 v_{f1} + m_2 v_{f2})}$$

V_{i1} & v_{f1} are initial and final velocity of object 1

V_{i2} & v_{f2} are initial and final velocity of object 2

Conservation of Momentum: within a system momentum is conserved

- Reminder: momentum is the product of mass and velocity **(p=mv)**

$$p_{1i} + p_{2i} = p_{1f} + p_{2f}$$

$$m_1v_{1i} + m_2v_{2i} = m_1v_{1f} + m_2v_{2f}$$

Momentum Before

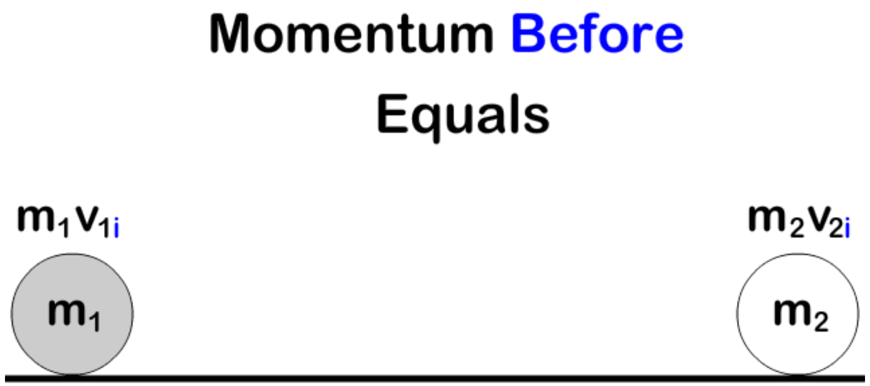
Equals

m_1 : first object mass
v_{1i} : first object initial velocity
v_{1f} : first object final velocity
m_2 : second object mass
v_{2i} : second object initial velocity
v_{2f} : second object final velocity

Elastic Collision

- Momentum <u>and</u> kinetic energy are conserved within the system
- The original objects that collide maintain their form and do not release heat in a **perfect elastic collision**
- **(objects maintain form and keep separate)**

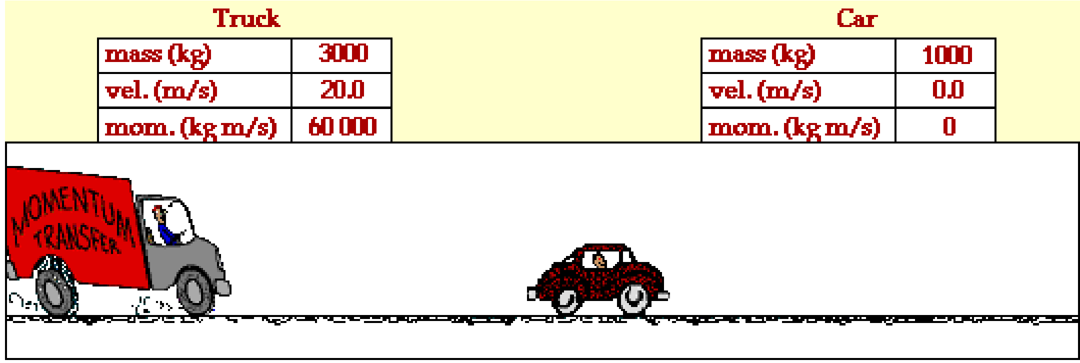
$$m_1v_{1i} + m_2v_{2i} = m_1v_{1f} + m_2v_{2f}$$



Inelastic Collision

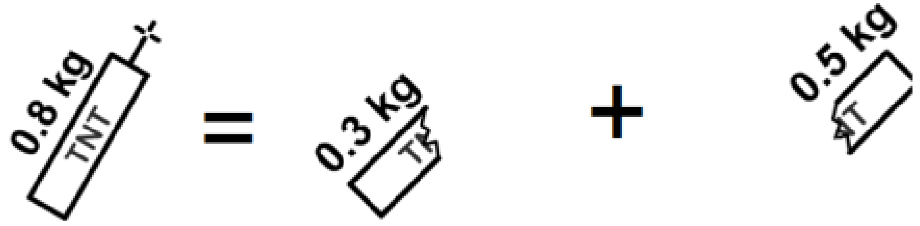
- Momentum <u>but there is lost in</u> kinetic energy is conserved within the system
- **(objects combine and stick together)**

$$m_1v_{1i} + m_2v_{2i} = v_f(m_1 + m_2)$$



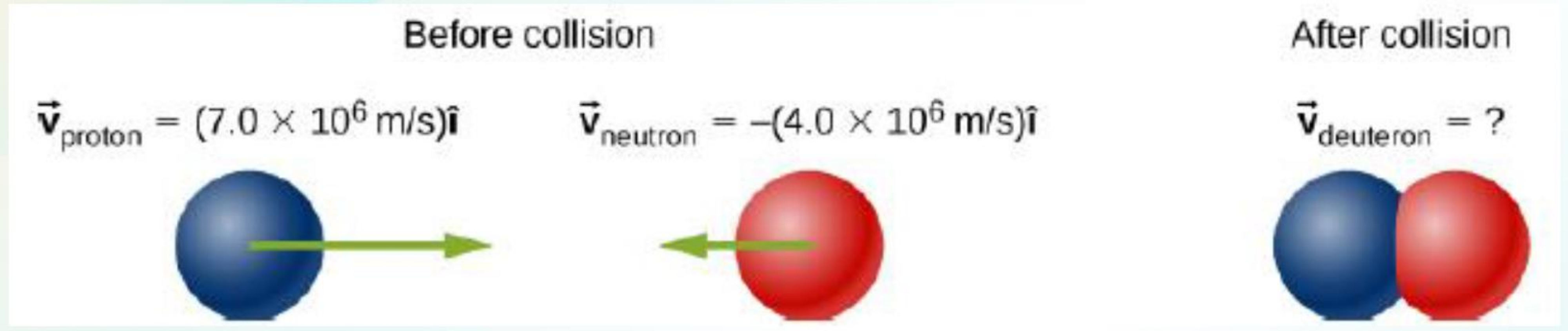
Example of Conservation of Momentum

A 0.80 kg firecracker is traveling through the air at 12 m/s to the right when it explodes. After the explosion, a 0.30 kg piece of it is flying to the left at 6.0 m/s. What is the mass of the other piece and how fast is it flying?



Example of Conservation of Momentum

A proton (mass 1.67×10^{-27} kg) collides with a neutron (with essentially the same mass as the proton) to form a particle called a deuteron. What is the velocity of the deuteron if it is formed from a proton moving with velocity 7.0×10^{6} m/s to the left and a neutron moving with velocity 4.0×10^{6} m/s to the right?



Example of Conservation of Momentum

Example of Conservation of Momentum

A 0.05 kg dart traveling 16 m/s hits a 0.15 kg movable target and sticks to it. How fast is the dart in the target moving together after the collision?

Example of Conservation of Momentum

A 0.1 kg pool ball traveling 2.5 m/s hits another 0.1 kg at rest. If the first ball stops after the elastic collision, how fast is the second now moving?

Example of Conservation f Momentum

- A 0.02 kg bullet is fired at 300 m/s into a 2 kg wooden block at rest. The bullet embeds itself in the block, and they move together after impact. What is their velocity after impact?

- How fast is an 85 kg receiver traveling 6 m/s to the right going after catching a 0.43 kg football traveling at 30 m/s right?

- A 95 kg pitcher at rest throws a 0.15 kg baseball 40 m/s to the right. How fast would the pitcher be going after the throw on a frictionless surface?

Module 8: Impulse and Momentum

Got any questions???

REFERENCES:

Ling, Samuel J., et.al (2018). University Physics Volume 1. OpenStax Rice University. Texas. Accessed at https://openstax.org/details/books/universityphysics- volume-1

The Physics Classroom (2020). Accessed at https://www.physicsclassroom.com

Professor Dave Explains (Mar 27, 2017). Work and Energy. Accessed at https://www.youtube.com/watch?v=zVRH9d5PW8g

The Physics Classroom. Work Concept Builder. Accessed at https://www.physicsclassroom.com/Concept-Builders/Work-and-Energy/Work/Concept-Builder

PhETInteractive Simulations. Hooke’s Law. Accessed at https://phet.colorado.edu/sims/html/hookes-law/latest/hookes-law_en.html