Honors Physics
Unit 4:
Momentum & Impulse

Slides

Momentum

What is momentum?

$$\vec{F}_{net} = m \cdot \vec{a} = m\frac{\Delta\vec{v}}{t} = m\frac{(\vec{v}_f - \vec{v}_i)}{t} = \frac{(m\vec{v}_f) - (m\vec{v}_i)}{t} = \frac{\vec{p}_f - \vec{p}_i}{t}$$

We give the quantity **mass times velocity** the name **momentum**. We use the symbol "*p*" for momentum.

Momentum

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

$$\vec{p} = m \cdot \vec{v}$$

The units for momentum are: $kg\frac{m}{s}$

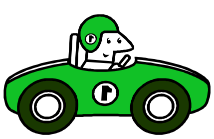
Momentum is the mass (kg) multiplied by velocity (m/s).

MOMENTUM

Momentum can be called…
"Magnitude or quantity of motion" of a moving object
"Inertia in motion" of a moving object

Momentum is the combination of "how much is moving" and 'how fast it is moving".

$$\vec{p} = m \cdot \vec{v}$$



v = 25 m/s

$p = 15{,}000 \ kg\frac{m}{s}$

m = 600 kg

A 600 kg automobile moving at 25 m/s will have 15,000 kg·m/s of momentum.

$$\vec{p} = m \cdot \vec{v}$$

Momentum is *proportional* to mass (inertia)

- The greater the mass, the greater the momentum.
- The smaller the mass, the lesser the momentum.

"How much" is in motion

$$\vec{p} = m \cdot \vec{v}$$

Momentum is *proportional* to the object's velocity.

- The greater the velocity, the greater the momentum.
- The lower the velocity, the lesser the momentum.

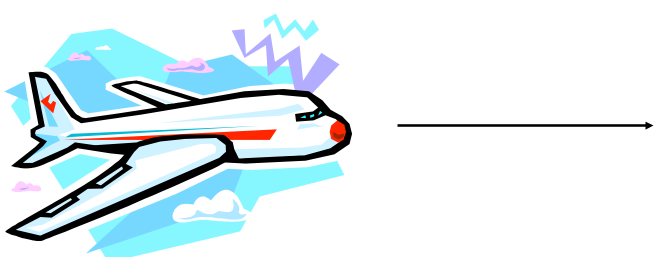
"How fast" → how much energy in motion.

What is momentum?

IMPORTANT: Momentum is a **vector** quantity (has magnitude *and* direction)

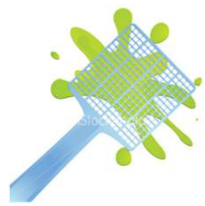
Direction is the same as the direction of the velocity

Jet: Very large mass & very large velocity = very large momentum (huge inertia and huge energy)



- More force needed to change velocity (speed up, slow down, or stop).
- More distance needed to change velocity (speed up, slow down, or stop).

Honeybee: Very small mass & very small velocity = very small momentum (small inertia and small energy)



A 100 gram plastic flyswatter will stop it with one swoop.

- Very small force needed to change velocity (speed up, slow down, or stop).
- Very short distances needed to change velocity (speed up, slow down, or stop).

TPQ (Though provoking question) time!

Consider the following. A car and a cargo truck are moving on the street.

- The mass of the car is 500 kg.
- The mass of the cargo truck is 3000 kg.

500 kg

3000 kg

Under which circumstance(s) would the car...

1. have a momentum less than the truck's momentum?
2. have a momentum equal to the truck's momentum?
3. have a momentum greater than the truck's momentum?

500 kg

3000 kg

Who has the most momentum?

Chad skateboards at 8.5 m/s. The mass of him and his board is 70 kg.

Melvin rides his bike at 7.0 m/s. The mass of him and his bike is 75 kg.

Enrique roller blades at 9.0 m/s. His mass is 64 kg.

Who has the most momentum?

Enrique's momentum is 576 kg·m/s.

Chad's momentum is 595 kg·m/s.

Melvin's momentum is 525 kg·m/s.

Calculating Change in Momentum ($\Delta\vec{p}$)

1. Calculate the initial momentum ($\vec{p}_i = m \cdot \vec{v}_i$)

2. Calculate the final momentum ($\vec{p}_f = m \cdot \vec{v}_f$)

3. $\Delta\vec{p} = \vec{p}_f - \vec{p}_i$

Rebounding

Two 2 kg objects are dropped and hit the ground with a velocity of -5 m/s. Object A comes to a rest when it hits the ground. Object B bounces and has a velocity of +2 m/s after hitting the ground. Which object has the larger change in momentum?

Rebounding (bouncing off a collision) causes a **greater** change in momentum than just stopping.

Kinetic Energy

Translational Kinetic Energy (KE): The energy of motion; the energy of an object moving at a given velocity from one position to another

$$KE = \frac{1}{2} \cdot m \cdot v^2$$

KE = kinetic energy (J)
m = mass (kg)
v = velocity (m/s)

All forms of energy are reported in units of Joules (J)

v

m

$$KE = \frac{1}{2} \cdot m \cdot v^2$$

Kinetic energy is proportional to mass and velocity squared.

- The greater the mass, the greater the KE.
- The smaller the mass, the lesser the KE.

Note that the velocity is squared:

- Double the velocity, 4-times the KE.
- Triple the velocity, 9-times the KE.

Who has the most translational kinetic energy?

Enrique roller blades at 9.0 m/s. His mass is 64 kg.

Chad skateboards at 8.5 m/s. The mass of him and his board is 70 kg.

Melvin rides his bike at 7.0 m/s. The mass of him and his bike is 75 kg.

Who has the most translational kinetic energy?

Enrique's momentum is 2592 J.

Chad's KE is 2529 J.

Melvin's momentum is 1837 J.

Momentum-Impulse Theorem

How do we reduce force during an impact?
How can we make cars safer during a car accident?
How can we prevent our phones from breaking when dropped?

Phone cases, Chipotle burrito phone cases, air bags, seat belts, automobile crumple zones, football helmets, stretchy rock climber ropes, catcher's mitts, bending your knees when you land from a jump

All these things reduce the force on an object during an impact.

How do they do it?

They all use a physics principle called the **impulse-momentum theorem**

Forces cause acceleration → acceleration causes change in velocity → change in velocity causes change in momentum

Therefore, **forces** cause changes in momentum

But…forces alone are not the whole story, **time** plays a role in changes in momentum as well

$$\vec{F}_{net} = m \cdot \vec{a} = m\frac{\Delta\vec{v}}{t} = m\frac{\vec{v}_f - \vec{v}_i}{t} = \frac{m\vec{v}_f - m\vec{v}_i}{t} = \frac{\vec{p}_f - \vec{p}_i}{t} = \frac{\Delta\vec{p}}{t}$$

$$\vec{F}_{net} = \frac{\Delta\vec{p}}{t}$$

$$\vec{F} \cdot t = \Delta\vec{p}$$

The Impulse-Momentum Theorem

Impulse

$$\text{Impulse} = \vec{F} \cdot t$$

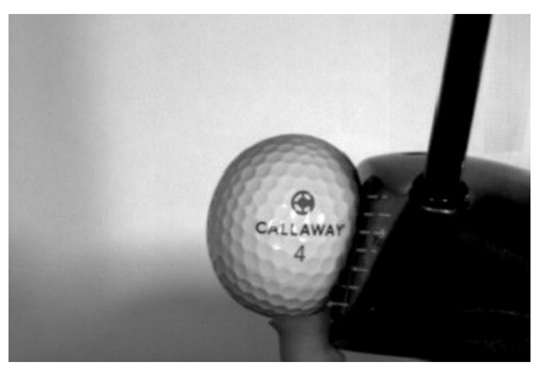
Impulse is defined as a force $\vec{F}$ applied to an object over a length of time t (called the **contact time**)

Impulse is a **vector** (magnitude & direction)

Unit: $\mathrm{N} \cdot \mathrm{s} = \frac{\mathrm{kg} \cdot \mathrm{m}}{\mathrm{s}}$

Examples

- Hammer hitting a nail
- Bat hitting a baseball
- Club hitting a golf ball



Impulse-Momentum Theorem

The **impulse-momentum theorem** says that the impulse on an object equals the change in its momentum

$$\underbrace{\vec{F} \cdot t}_{\text{Impulse}} = \underbrace{\Delta \vec{p}}_{\text{Change in momentum}}$$

Momentum and Collisions **Section 1**

Classroom Practice Problems

- A 1350 kg car has a velocity of 22.0 m/s to the north. When braking rapidly, it stops in 4.50 s.
  - What was the momentum of the car before braking?
  - What is the magnitude of the force required to stop the car?
- Answers:
  - 2.97×10^4 kg • m/s to the north
  - 6.60×10^3 N

< Back Next > Preview Main

What's the relationship between the applied force and the contact time for a given change in the momentum (for example, 100 kg·m/s)?

$$\Delta\vec{p} = 100\ \frac{\mathrm{kg} \cdot \mathrm{m}}{\mathrm{s}} = \vec{F} \cdot t$$

Force	Time
100	1
50	2
25	4
10	10
4	25
2	50
1	100
0.1	1000

What happens to the contact time as the force decreases?

What happens to the contact time as the force increases?

For a given change in momentum (equivalently, a given impulse), the **force** and the **contact time** are **inversely proportional**

- If the **contact time** is very small (e.g., instantaneous, sudden, jerking), the **force** causing the acceleration is very, very large.
- If the **contact time** is longer (e.g., cushioned or slowed gradually), the **force** causing the acceleration is much smaller.

Phone cases, Chipotle burrito phone cases, air bags, seat belts, automobile crumple zones, football helmets, stretchy rock climber ropes, catcher’s mitts, bending your knees when you land from a jump

All these things reduce the force on an object during an impact.

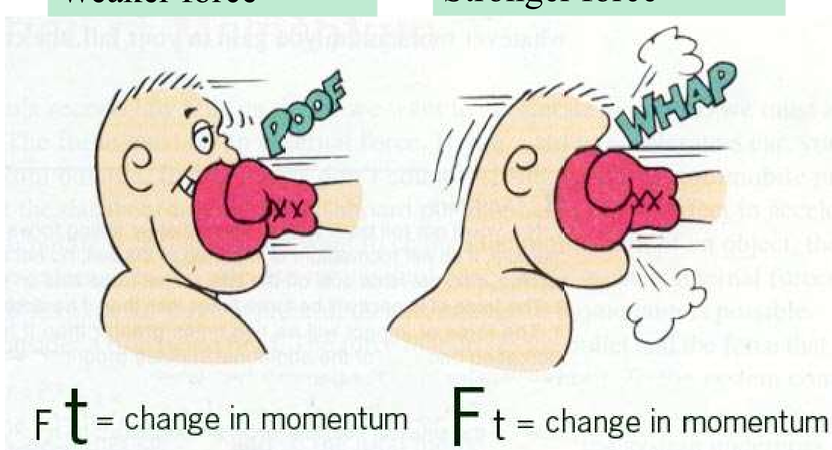
How do they do it?

They all reduce **force** by increasing the **contact time** of the impact.

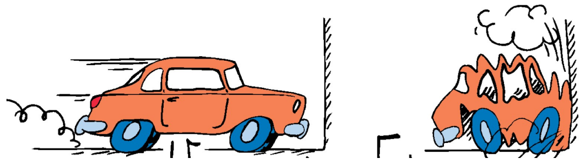
The punch causes the **SAME IMPULSE**, however, the impact force differs due to the contact time.

Longer contact time
Weaker force

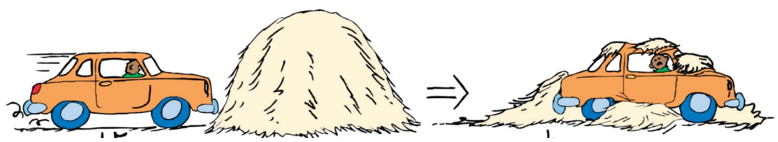
Shorter contact time
Stronger force



Shorter contact time with a sudden stop. Stronger force at impact.



Longer contact time with a gradual stop. Weaker force.

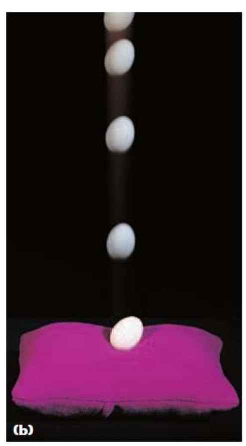


The car experiences the **SAME IMPULSE**, however, the impact force differs due to the contact time.

The falling egg experiences the **SAME IMPULSE**, however, the impact force differs due to the contact time.

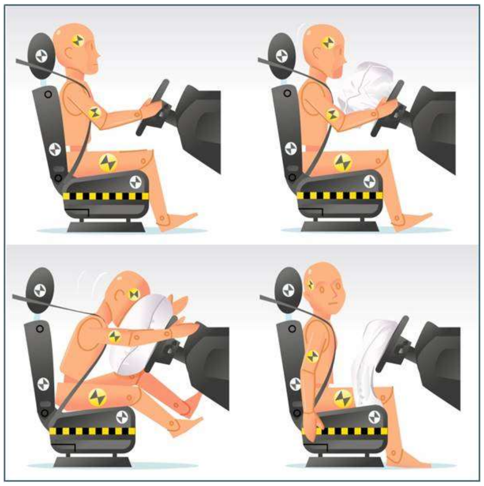
Shorter contact time
Stronger force at impact with floor.

Longer contact time
Weaker force at impact in pillow.



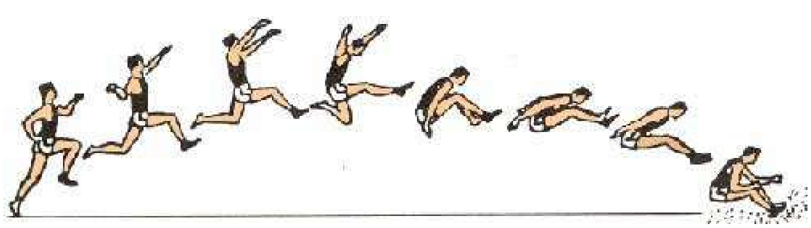
Both eggs go from motion to a complete stop. The pillow makes a longer contact time, thus reducing the force of impact on the eggshell.

The crash test dummy's head experiences the **SAME IMPULSE** *with or without the air bag or shoulder restraints*, however, the impact force of its face differs due to the contact time.



Shoulder restraints and airbags increase the contact time between the impact of the automobile and the head/body's collision with the dashboard and steering wheel.

When landing a jump, bend your knees. Bending the knees increases the time for the body to come to rest, reducing impact force on legs and ankles.



Long jumpers land in the sand or sawdust pit. The sand and sawdust distributes the momentum of impact as it scatters, extending the jumper's rest time by 0.5-1 second. This reduces the jerk on the body during landing.

Momentum and Collisions Section 1

Classroom Practice Problems

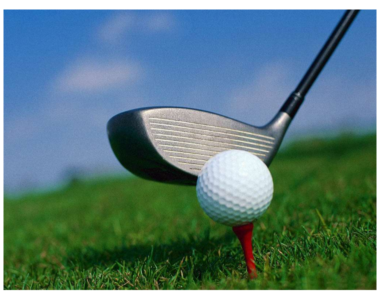
- A 65 kg passenger in a car travels at a speed of 8.0 m/s. If the passenger is stopped by an airbag in 0.75 s, how much force is required?
  - Answer: 6.9×10^2 N
- If the car does not have an air bag and the passenger is instead stopped in 0.026 s when he strikes the dashboard, by what factor does the force increase?
  - Answer: **F** = 2.0×10^4 N so it is 29 times greater

< Back Next > Preview Main

The baseball player hits the baseball with the bat. The ball is initially moving at 40 m/s. After it is hit, the ball moves at -40 m/s. The contact time between the bat and ball is 0.15 seconds. The mass of the baseball is 0.145 kg

- Calculate the initial momentum.
- Calculate the final momentum.
- Calculate the acceleration.
- Calculate the impulse acting upon the ball.
- Calculate the force of impact between the ball and the baseball bat.

Initial momentum.	$p_0 = m \cdot v_0 = 0.145\,kg \cdot 40\,{}^{m}\!/\!_{s} = 5.8\,kg\,{}^{m}\!/\!_{s}$
Final momentum.	$p_f = m \cdot v_f = 0.145\,kg \cdot -40\,{}^{m}\!/\!_{s} = -5.8\,kg\,{}^{m}\!/\!_{s}$
Acceleration.	$a = \frac{v_f - v_0}{t} = \frac{-40 - 40\,{}^{m}\!/\!_{s}}{0.15s} = -533\,{}^{m}\!/\!_{s^2}$
Impulse	$J = \Delta p = p_f - p_0 = -5.8 - 5.8\,kg\,{}^{m}\!/\!_{s} = -11.6\,kg\,{}^{m}\!/\!_{s}$
Force	$F = m \cdot a = \frac{\Delta p}{t} = \frac{-11.6kg\,{}^{m}\!/\!_{s}}{0.15s} = -77.3N$



A golf ball has a mass of 0.10 kg. It sits upon the tee. The golf club strikes the ball, accelerating the ball to 100 m/s. The contact time between the club and the ball is 0.1 seconds.

- Calculate the initial momentum.
- Calculate the final momentum.
- Calculate the acceleration.
- Calculate the impulse acting upon the ball.
- Calculate the force of impact between the ball and the club.

Initial momentum. $p_0 = m \cdot v_0 = 0.10\,kg \cdot 0\,{}^{m}\!/_{s} = 0\,kg\,{}^{m}\!/_{s}$

Final momentum. $p_f = m \cdot v_f = 0.10\,kg \cdot 100\,{}^{m}\!/_{s} = 10\,kg\,{}^{m}\!/_{s}$

Acceleration. $a = \dfrac{v_f - v_0}{t} = \dfrac{100 - 0\,{}^{m}\!/_{s}}{0.1s} = 1000\,{}^{m}\!/_{s^2}$

Impulse $J = \Delta p = p_f - p_0 = 10 - 0\,kg\,{}^{m}\!/_{s} = 10\,kg\,{}^{m}\!/_{s}$

Force $F = m \cdot a = \dfrac{J}{t} = \dfrac{10kg\,{}^{m}\!/_{s}}{0.1s} = 100N$

A car crashed through a brick wall. The velocity of the car immediately before impact was 16 m/s. The velocity of the immediately car after impact was 6 m/s. The impact time was 1.22 sec. The car's mass is 450 kg.

- Calculate the initial momentum.
- Calculate the final momentum.
- Calculate the acceleration.
- Calculate the impulse acting upon the car.
- Calculate the force of impact between car and the wall.

Initial momentum. $p_0 = m \cdot v_0 = 450\,kg \cdot 16\,{}^{m}\!/_{s} = 7200\,kg\,{}^{m}\!/_{s}$

Final momentum. $p_f = m \cdot v_f = 450\,kg \cdot 6.0\,{}^{m}\!/_{s} = 2700\,kg\,{}^{m}\!/_{s}$

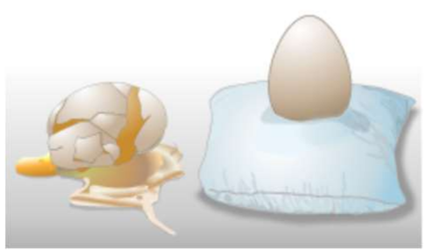
Acceleration. $a = \dfrac{v_f - v_0}{t} = \dfrac{6-16\,{}^{m}\!/_{s}}{1.22s} = -8.19\,{}^{m}\!/_{s^2}$

Impulse $J = \Delta p = p_f - p_0 = 2700 - 7200\,kg\,{}^{m}\!/_{s} = -4500\,kg\,{}^{m}\!/_{s}$

Force $F = m \cdot a = \dfrac{J}{t} = \dfrac{-4500kg\,{}^{m}\!/_{s}}{1.22s} = -3688N$

Two eggs were dropped from 10 m above the ground. One egg landed to rest on a cushioned pillow. The other egg hit the sidewalk without any cushion. The mass of each egg was 0.080 kg. Both were moving 14.8 m/s immediately before impact.

The egg that impacted the sidewalk came to rest in 0.04 seconds.



The egg that landed on the cushion came to rest in 0.72 seconds.

- Calculate the initial momentum.
- Calculate the final momentum.
- Calculate the acceleration.
- Calculate the impulse acting upon the eggs.
- Calculate the force of impact acting upon the eggs.

	Without pillow	With pillow
Initial momentum.	$p_0 = -1.184\ kg\ {}^{m}\!/\!{}_{s}$	$p_0 = -1.184\ kg\ {}^{m}\!/\!{}_{s}$
Final momentum.	$p_f = 0\ kg\ {}^{m}\!/\!{}_{s}$	$p_f = 0\ kg\ {}^{m}\!/\!{}_{s}$
Acceleration.	$a = 29.6\ {}^{m}\!/\!{}_{s^2}$	$a = 1.64\ {}^{m}\!/\!{}_{s^2}$
Impulse	$J = \Delta p = 1.184\ kg\ {}^{m}\!/\!{}_{s}$	$J = \Delta p = 1.184\ kg\ {}^{m}\!/\!{}_{s}$
Force	$F = 2.36\ N$	$F = 0.13\ N$

Law of Conservation of Momentum

Definition of System

In physics, a **system** is defined as some portion of the Universe that you are choosing to focus on.

- Can be one object, multiple objects, a region of space
- Examples: you, two billiard balls on a table, the classroom

Definition of System

A system is **closed** if nothing enters or leaves the system and there are no forces acting on the system from sources outside the system (no external forces)

A system is **open** if objects can enter or leave the system or there are external forces acting on the system

<u>Law of Conservation of Momentum</u>

In a *closed* system, the *total momentum* of interacting objects remains *constant*.

IN OTHER WORDS

If objects interact, the sum of the momenta of all objects before the collision must equal the sum of momenta of all objects after the collision.

TOTAL p (before) = TOTAL p (after)

Law of Conservation of Momentum

- Consequence of Newton's 3rd Law
  - All forces come in pairs that have equal magnitude, opposite direction, and act on different objects

Examples of Conservation of Momentum

- Recoil
- Explosions
- Rockets

Conservation of Momentum Example

Before explosion:

Grenade is at rest.
Momentum is zero.

After explosion:

Sum of momentum of all flying pieces is still zero.

Solving Conservation of $\vec{p}$ Problems

1. Find total initial momentum
2. Find total final momentum
3. Set them equal and solve for your unknown

$$\vec{p}_{1,i} + \vec{p}_{2,i} = \vec{p}_{1,f} + \vec{p}_{2,f}$$

$$m_1\vec{v}_{1,i} + m_2\vec{v}_{2,i} = m_1\vec{v}_{1,f} + m_2\vec{v}_{2,f}$$

Elastic & Inelastic Collisions

<u>Law of Conservation of Momentum</u>

In a *closed* system, the *total momentum* of interacting objects remains *constant*.

IN OTHER WORDS

If objects interact (collide), the sum of the momenta of all objects before the collision must equal the sum of momenta of all objects after the collision.

TOTAL p (before) = TOTAL p (after)

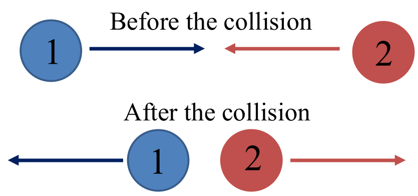
Elastic collisions = perfect collisions

Rigid objects collide and rebound off of each other without damage, without friction or heat at impact, without sticking together, and without loss of kinetic energy.

- Momentum is conserved.
- Kinetic energy is conserved.

Note: in the real world, truly perfect collisions never happen.

Momentum is conserved: The sum of the momenta before the collision must equal the sum of the momenta after the collision.

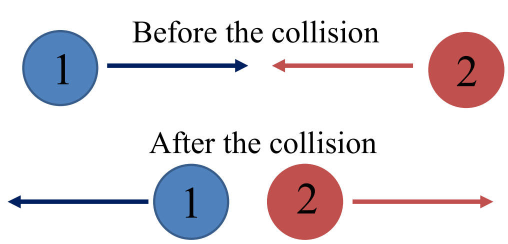


TOTAL p (before) = TOTAL p (after)

$$p_{1,\mathrm{i}} + p_{2,\mathrm{i}} = p_{1,\mathrm{f}} + p_{2,\mathrm{f}}$$

$$(m_1 \cdot v_1) + (m_2 \cdot v_2) = (m_1 \cdot v_1) + (m_2 \cdot v_2)$$

Kinetic energy is conserved: The sum of the KEs of objects before the collision must equal the sum of the KEs of the objects after the collision.



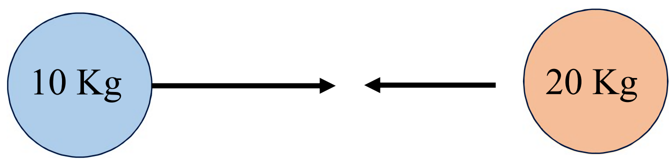
TOTAL KE (before) = TOTAL KE (after)

$$KE_{1,\mathrm{i}} + KE_{2,\mathrm{i}} = KE_{1,\mathrm{f}} + KE_{2,\mathrm{f}}$$

RULE 1. The object with the ***greater momentum before the collision*** will transfer some of its momentum to the object with the ***lesser momentum before the collision***.

Less momentum before collision—gains momentum from other object during collision

More momentum before collision—loses momentum to other object during collision

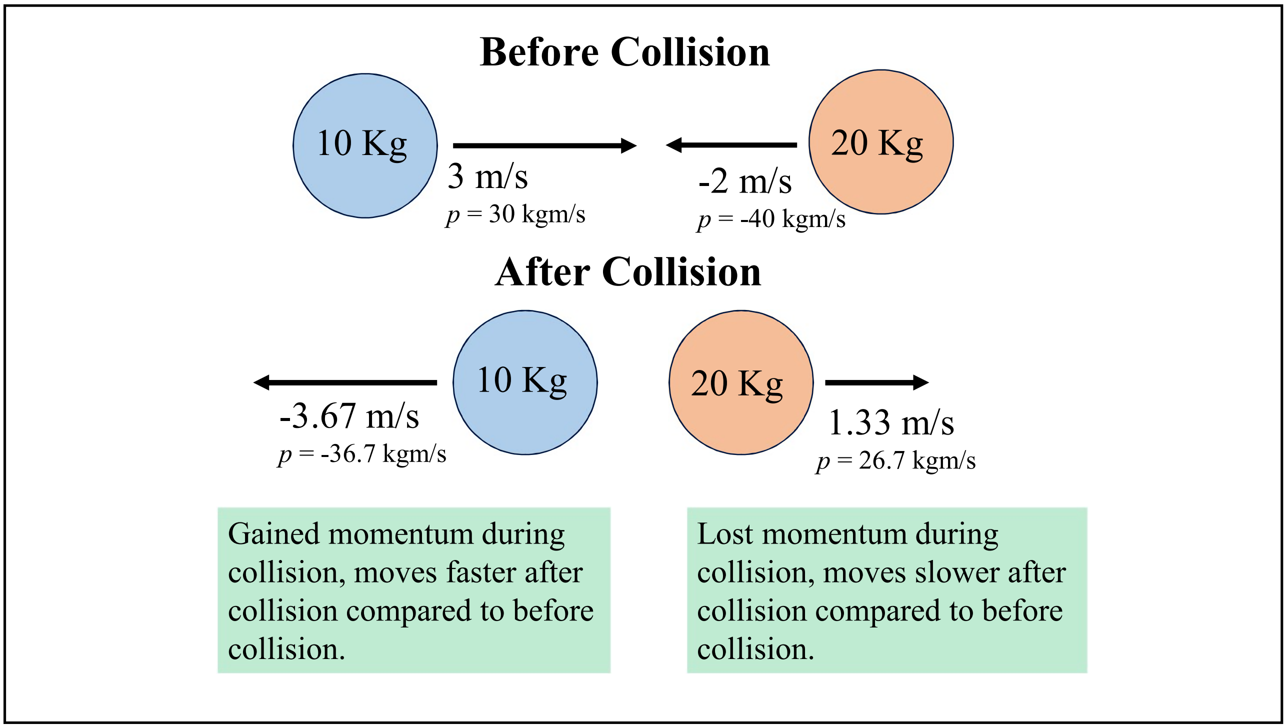


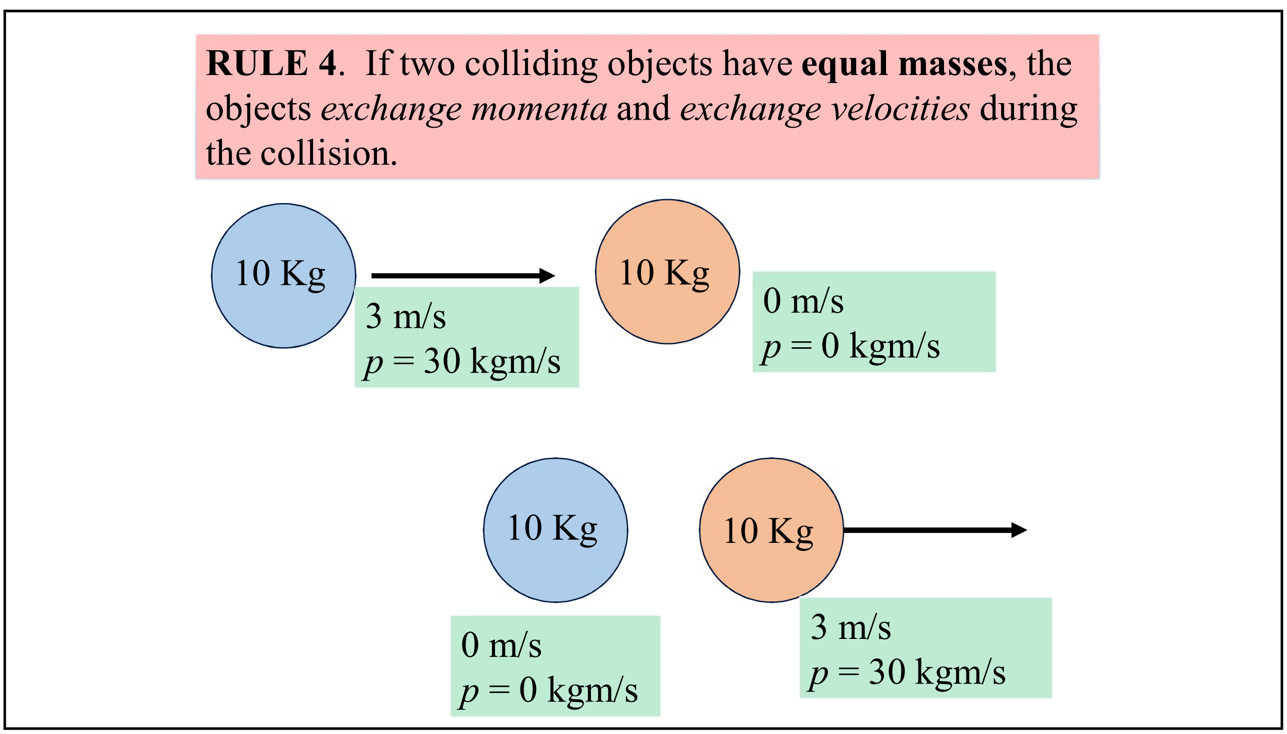
$v = 3$ m/s
$p = 30$ kg m/s

$v = -2$ m/s
$p = -40$ kg m/s

RULE 2. The object with the ***greater momentum*** *before the collision* will experience a decrease in speed after the collision. It will be *moving slower after the collision* compared to its speed before the collision.
(Transferred momentum to other object)

RULE 3. The object with the ***lesser momentum*** *before the collision* will experience an increase in speed after the collision. It will be *moving faster after the collision* compared to its speed before the collision.
(Gained momentum from other object)


Before Collision
10 Kg
3 m/s
p = 30 kgm/s
20 Kg
-2 m/s
p = -40 kgm/s
After Collision
10 Kg
-3.67 m/s
p = -36.7 kgm/s
20 Kg
1.33 m/s
p = 26.7 kgm/s
Gained momentum during collision, moves faster after collision compared to before collision.
Lost momentum during collision, moves slower after collision compared to before collision.


RULE 4. If two colliding objects have **equal masses**, the objects *exchange momenta* and *exchange velocities* during the collision.
10 Kg
3 m/s
p = 30 kgm/s
10 Kg
0 m/s
p = 0 kgm/s
10 Kg
0 m/s
p = 0 kgm/s
10 Kg
3 m/s
p = 30 kgm/s

How to solve for final velocities of two colliding objects after an elastic collision:

$$v_{1f} = \frac{(m_1 - m_2)\cdot v_{1i} + (2m_2 \cdot v_{2i})}{m_1 + m_2}$$

$$v_{2f} = \frac{(m_2 - m_1)\cdot v_{2i} + (2m_1 \cdot v_{1i})}{m_1 + m_2}$$

#1. Two objects have an elastic collision.

Before collision: Object 1 has a mass of 20 kg and moves to the right with a velocity of 5 m/s. Object 2 has a mass of 10 kg and is stationary.

- Predict the momentum transfer (who transfers momentum to whom).
- What will happen to Object 1's velocity after the collision?
- What will happen to Object 2's velocity after the collision?

- Predict the momentum transfer (who transfers momentum to whom).

Object #1 will transfer momentum to Object #2.

- What will happen to Object 1's velocity after the collision?

Object #1 will move slower after the collision compared to its velocity before the collision.

- What will happen to Object 2's velocity after the collision?

Object #2 will move faster after the collision compared to its velocity before the collision.

#2. Two objects have an elastic collision.

Before collision: Object 1 has a mass of 20 kg and moves to the right with a velocity of 5 m/s. Object 2 has a mass of 15 kg and moves to the right with a velocity of 3 m/s.

- Predict the momentum transfer (who transfers momentum to whom).
- What will happen to Object 1's velocity after the collision?
- What will happen to Object 2's velocity after the collision?

- Predict the momentum transfer (who transfers momentum to whom).

Object #1 will transfer momentum to Object #2.

- What will happen to Object 1's velocity after the collision?

Object #1 will move slower after the collision compared to its velocity before the collision.

- What will happen to Object 2's velocity after the collision?

Object #2 will move faster after the collision compared to its velocity before the collision.

#3. Two objects have an elastic collision.

Before collision: Object 1 has a mass of 20 kg and moves to the right with a velocity of 3 m/s. Object 2 has a mass of 15 kg and moves to the left with a velocity of -5 m/s.

- Predict the momentum transfer (who transfers momentum to whom).
- What will happen to Object 1's velocity after the collision?
- What will happen to Object 2's velocity after the collision?

- Predict the momentum transfer (who transfers momentum to whom).

Object #2 will transfer momentum to Object #1.

- What will happen to Object 1's velocity after the collision?

Object #1 will move faster after the collision compared to its velocity before the collision.

- What will happen to Object 2's velocity after the collision?

Object #2 will move slower after the collision compared to its velocity before the collision.

#4. Two objects have an elastic collision.

Before collision: Object 1 has a mass of 20 kg and moves to the right with a velocity of 3 m/s. Object 2 has a mass of 20 kg and moves to the left with a velocity of -5 m/s.

- Predict the momentum transfer (who transfers momentum to whom).
- What will happen to Object 1's velocity after the collision?
- What will happen to Object 2's velocity after the collision?

- Predict the momentum transfer (who transfers momentum to whom).
  Object #2 will transfer momentum to Object #1.

- What will happen to Object 1's velocity after the collision? **Object #1 will exchange momentums and velocities with Object #2 during collision. Object #1 will move at -5.0 m/s**

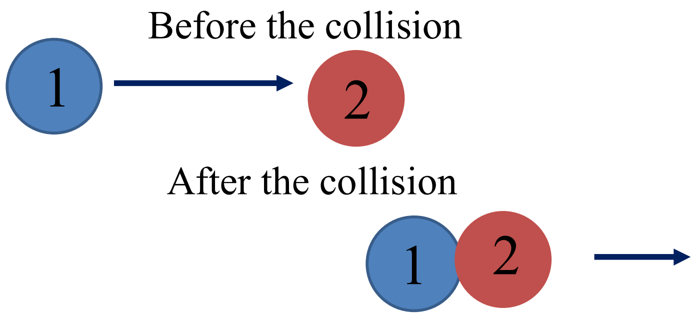
- What will happen to Object 2's velocity after the collision? **Object #2 will exchange momentums and velocities with Object #1 during collision. Object #2 will move at 3.0 m/s.**

Inelastic collisions = imperfect collisions

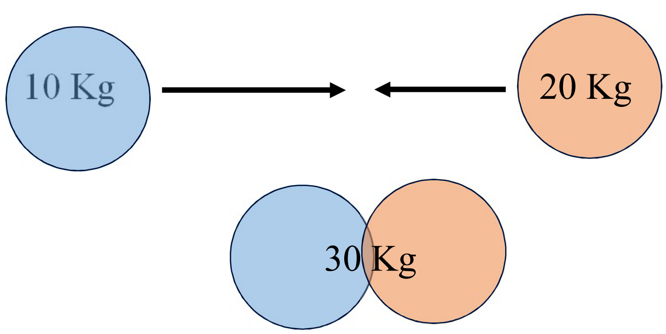
Objects collide and are damaged/deformed during collision

Perfectly Inelastic Collision: the objects stick together after the collision

- Momentum is conserved.
- Kinetic energy is lost during collision. KE before collision is greater than KE after collision.

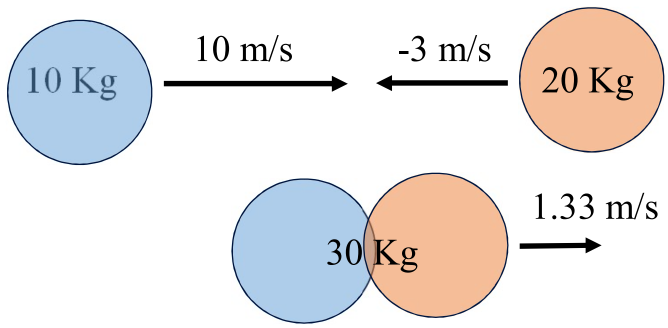


RULE 1. The mass of the conjoined objects after the collision is the sum of the masses of the objects before the collision. Mass is conserved during collision.



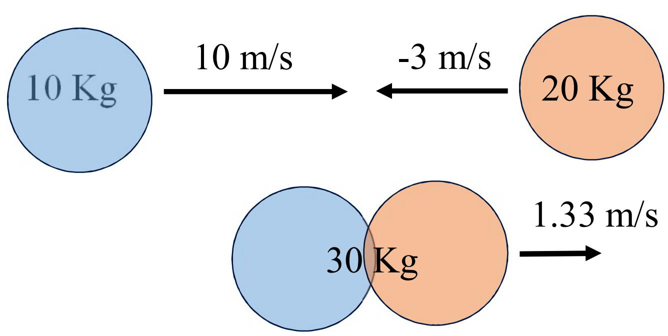
The mass of the conjoined objects is 30 kg, the sum of the 10 kg and 20 kg colliding masses.

RULE 2. The velocity of the conjoined objects after the collision must be the ***mass-average*** of the velocities of the objects before the collision. The magnitude of the velocity after collision must be "***in between***" the velocities of the two objects before the collision.



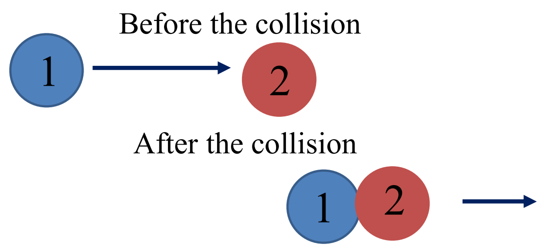
1.33 m/s is "in-between" 10 m/s and -3 m/s.

RULE 3. After the collision, the conjoined objects will move in the same direction as the object with the most momentum before the collision.



The conjoined objects will move right after the collision because the blue circle had the greater momentum before the collision.

Inelastic Collisions (conjoined)
Law of Conservation of Momentum

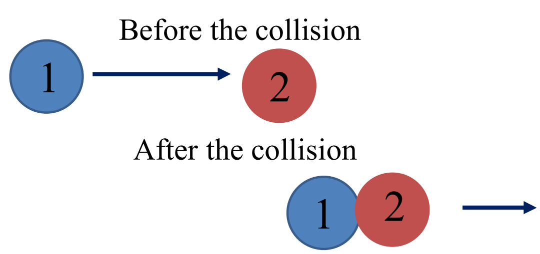


TOTAL p (before) = TOTAL p (after)

$$p_{1,i} + p_{2,i} = p_{12,f}$$

$$(m_1 \cdot v_1) + (m_2 \cdot v_2) = m_{12} \cdot v_{12}$$

Inelastic Collisions (conjoined)
Kinetic Energy is NOT conserved.



$$\text{TOT KE}_{(\text{before})} > \text{TOT KE}_{(\text{after})}$$

$$\mathbf{KE_1 + KE_2 > KE_{12}}$$

#1. Two objects have an inelastic collision.
Before collision: Object 1 has a mass of 20 kg and moves to the right with a velocity of 5 m/s. Object 2 has a mass of 10 kg and is stationary.

- Predict the velocity and direction of the conjoined motion after the collision.

#2. Two objects have an inelastic collision.
Before collision: Object 1 has a mass of 20 kg and moves to the right with a velocity of 5 m/s. Object 2 has a mass of 15 kg and moves to the right with a velocity of 3 m/s.

- Predict the momentum transfer the direction of the conjoined object’s motion after the collision.

#3. Two objects have an inelastic collision.
Before collision: Object 1 has a mass of 20 kg and moves to the right with a velocity of 3 m/s. Object 2 has a mass of 15 kg and moves to the left with a velocity of -5 m/s.

- Predict the momentum transfer the direction of the conjoined object's motion after the collision.

- #1. Predict the velocity and direction of the conjoined motion after the collision.

Objects will conjoin and move to the right. The velocity will be between 0 m/s and 5.0 m/s.

- #2. Predict the velocity and direction of the conjoined motion after the collision.

Objects will conjoin and move to the right. The velocity will be between 3.0 m/s and 5.0 m/s.

- #3. Predict the velocity and direction of the conjoined motion after the collision.

Objects will conjoin and move to the left. The velocity will be between 3.0 m/s and -5.0 m/s.