# Chapter 6

# MOMENTUM

# Outline

- Momentum
- Impulse
- Bouncing
- Conservation of Momentum
- Collisions
- More Complicated Collisions

# Momentum

- Momentum is a property of moving things.
- It means **inertia in motion**
- more specifically, mass of an object multiplied by its velocity.
- in equation form:

$$\text{Momentum} = \text{mass} \times \text{velocity}$$

$$P = m\,v$$

- Momentum is a vector.

# Momentum

$P = m v$

Example:

- A moving boulder has more momentum than a stone rolling at the same speed.
- A fast boulder has more momentum than a slow boulder.
- A boulder at rest has no momentum.

A moving object has

A. momentum.
A. energy.
B. speed.
C. All of the above.

A moving object has

A. momentum.
A. energy.
B. speed.
C. **All of the above.**

*Comment*:
We will see in the next chapter that energy in motion is called kinetic energy.

When the speed of an object is doubled, its momentum

A. remains unchanged in accord with the conservation of momentum.

A. doubles.

B. quadruples.

C. decreases.

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P = mv

When momentum of an object changes, either mass or velocity or both change.
It mass doesn't change, then velocity must change to have a <u>change in momentum</u>.

When the velocity changes, an acceleration occurs.

Because acceleration = force / mass , that means there must be a <u>force</u> to produce acceleration.

Higher the force, higher the acceleration , higher the change in velocity, and as a result, higher the change in momentum.

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

$\Delta P = Ft$

In addition to force, the time that the force acts on an object is also important.

When you apply a force for a certain period of time, the change in momentum occurs.

If you apply the same force for a longer period of time, the change in momentum is greater.

Both force and the time interval are important in changing momentum.

# Impulse

- Product of force and time (force × time)
- In equation form: Impulse = *Ft*
- **Not** something an object *has*
- Impulse is what an object *provide* or what it can *experience* when it interacts with another object.

# Impulse = Change in Momentum

The greater the impulse exerted on something, the greater the change in momentum.

- In equation form: <u>$Ft = \Delta(mv)$</u>

# Impulse

Examples:

<u>Impulse = *Ft*</u>

<u>$Ft = \Delta(mv)$</u>

- A brief force applied over a short time interval produces a smaller change in momentum than the same force applied over a longer time interval.

or

- If you push with the same force for twice the time, you impart twice the impulse and produce twice the change in momentum.

When the force that produces an impulse acts for twice as much time, the impulse is

Impulse = $Ft$

A. not changed.

A. doubled.

B. quadrupled.

C. halved.

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# Impulse = Change in Momentum

$I = Ft = \Delta(mv)$

What happens when we

1)Increase momentum?

2)Decrease momentum over a long time?

3)Decrease momentum over a short time?

# Impulse = Change in Momentum

$I = Ft = \Delta(mv)$

- **<u>Case 1: increasing momentum</u>**

-

1) To increase the momentum

1) Apply the greatest force for as long as possible and extend the time of contact.

2) Force can vary throughout the duration of contact.

Examples:

- Golfer swings a club and follows through.

- Baseball player hits a ball and follows through.

# Impulse = Change in Momentum

$I = Ft = \Delta(mv)$

- **Case 2: decreasing momentum over a long time**

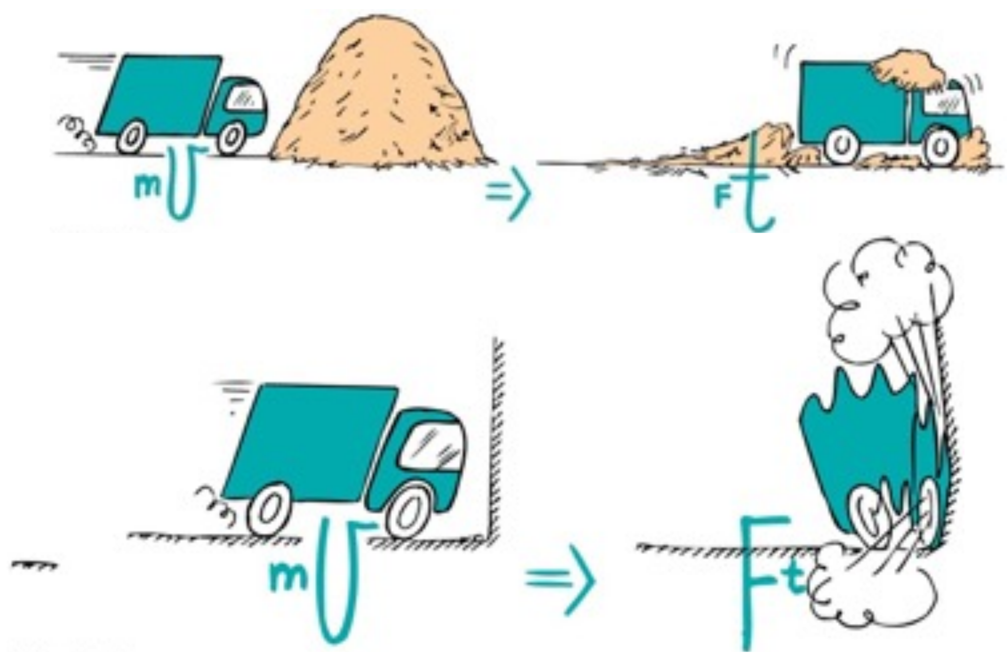
1) extend the time during which momentum is reduced.

Example: If you were in a car that was out of control and you had to choose between hitting a concrete wall or a haystack, what would you choose?

# Impulse = Change in Momentum

When a car is out of control, it is better to hit a haystack than a concrete wall.

Physics reason: Same impulse either way, but extension of hitting time reduces the force.



A fast-moving car hitting a haystack or a cement wall produces vastly different results.

1. Do both experience the same change in momentum?
2. Do both experience the same impulse?
3. Do both experience the same force?

A. Yes for all three

A. Yes for 1 and 2

B. No for all three

C. No for 1 and 2

$I = Ft = \Delta(mv)$

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1. Do both experience the same change in momentum?
2. Do both experience the same impulse?
3. Do both experience the same force?

$I = Ft = \Delta(mv)$

A. Yes for all three
A. **Yes for 1 and 2**
B. No for all three
C. No for 1 and 2

*Explanation*:
Although stopping the momentum is the same whether done slowly or quickly, the force is vastly different. Be sure to distinguish among momentum, impulse, and force.

When a dish falls, will the <u>change in momentum</u> be less if it lands on a carpet than if it lands on a hard floor? (Careful!)

$I = Ft = \Delta(mv)$

A. No, both are the same.

A. Yes, less if it lands on the carpet.

B. No, less if it lands on a hard floor.

C. No, more if it lands on a hard floor.

When a dish falls, will the <u>change in momentum</u> be less if it lands on a carpet than if it lands on a hard floor? (Careful!)

**A. No, both are the same.**

$I = Ft = \Delta(mv)$

A. Yes, less if it lands on the carpet.

B. No, less if it lands on a hard floor.

C. No, more if it lands on a hard floor.

*Explanation*:

**The momentum becomes zero in both cases, so both change by the same amount**. Although the momentum change and impulse are the same, the force is less when the time of momentum change is extended. Be careful to distinguish among force, impulse, and momentum.

# Impulse = Change in Momentum

$I = Ft = \Delta(mv)$

- **Case 3: decreasing momentum over a short time**

  A. short time interval produces large force.

Example: Karate expert splits a stack of bricks by bringing her arm and hand swiftly against the bricks with considerable momentum. **Time of contact is brief and force of impac**t

# Bouncing

Impulses are generally greater when objects bounce.

Example:

Catching a falling flower pot from a shelf with your hands. You provide the impulse to reduce its momentum to zero. If you throw the flower pot up again, you provide an additional impulse. This "double impulse" occurs when something bounces.

$$I = Ft = \Delta(mv)$$

# Bouncing

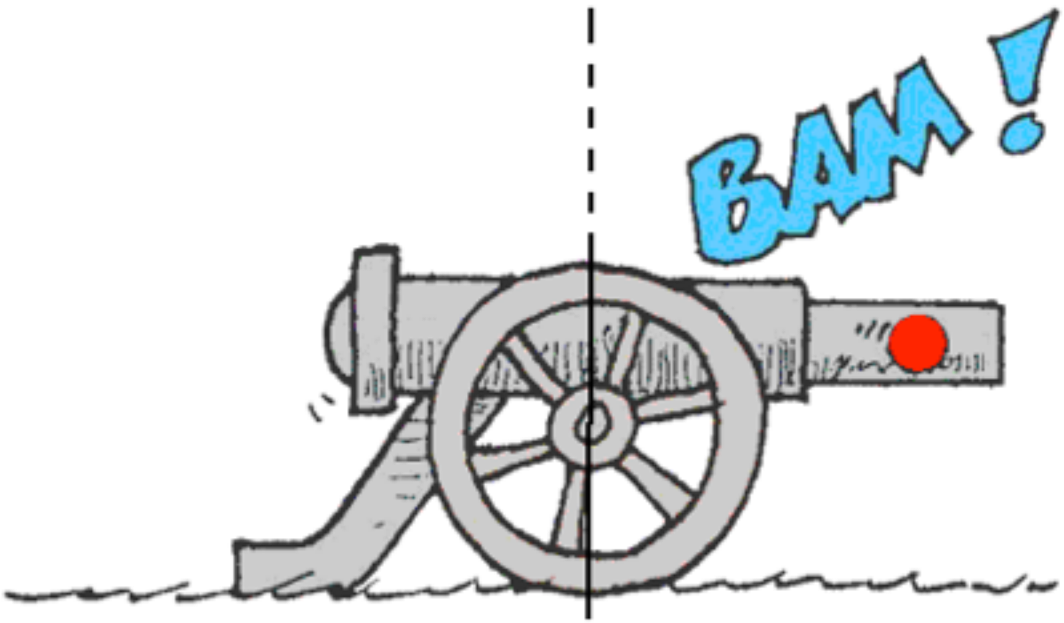
Pelton wheel designed to “bounce” water when it makes a U-turn on impact with the curved paddle

Gets energy from the momentum of moving water. When water bounces from curved paddles, it increases the impulse on the wheel.

# Conservation of Momentum

Law of conservation of momentum:

In the absence of an external force, the momentum of a system remains unchanged.



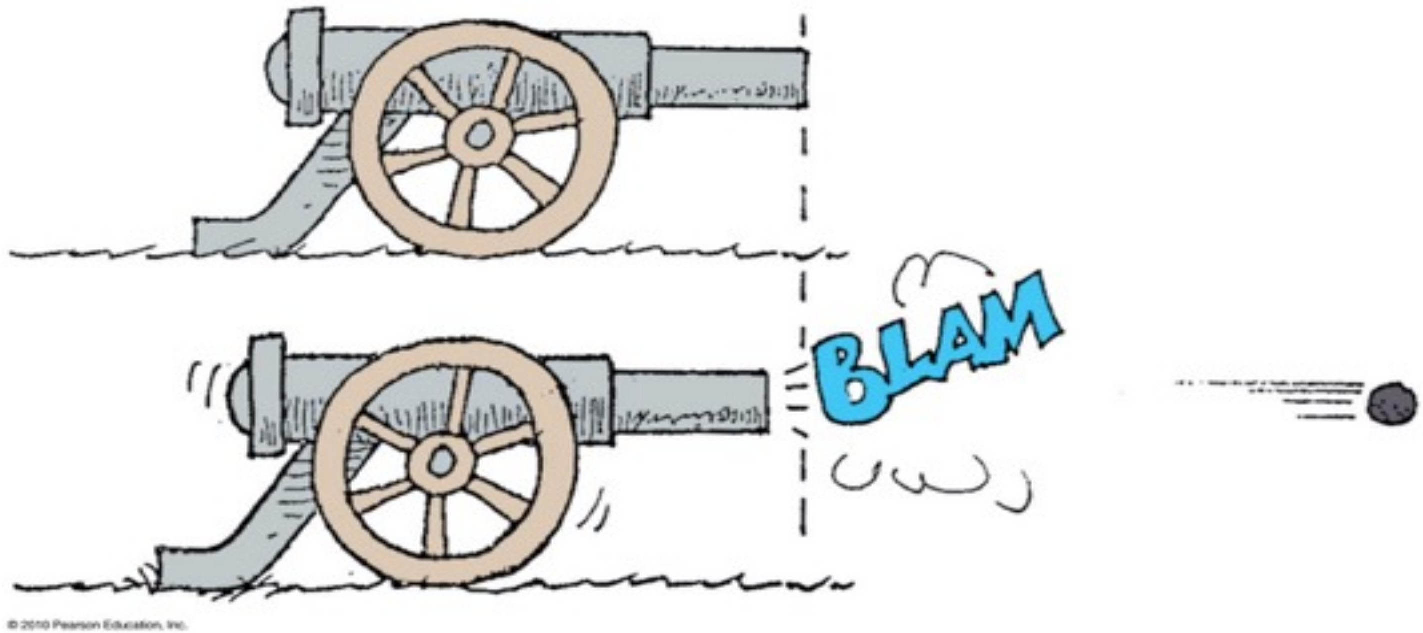
# Conservation of Momentum

Examples:

A. When a cannon is fired, the force on the cannonball inside the cannon barrel is equal and opposite to the force of the cannonball on the cannon.

B. The cannonball gains momentum, while the cannon gains an equal amount of momentum in the opposite direction—the cannon recoils.

When no external force is present, no external impulse is present, and no change in momentum is possible.




Momentum of the system before firing = 0

Force on cannon = force on cannonball (Newton’s 3rd Law)
Time is the same. Therefore, impulse or change in momentum is the same.

Momentum of the cannonball = momentum of the cannon in opposite direction

Momentum of the system after firing = 0

**Momentum is conserved !!!**

# Collisions

For all collisions in the absence of external forces,

- net momentum before collision equals net momentum after collision.
- in equation form:

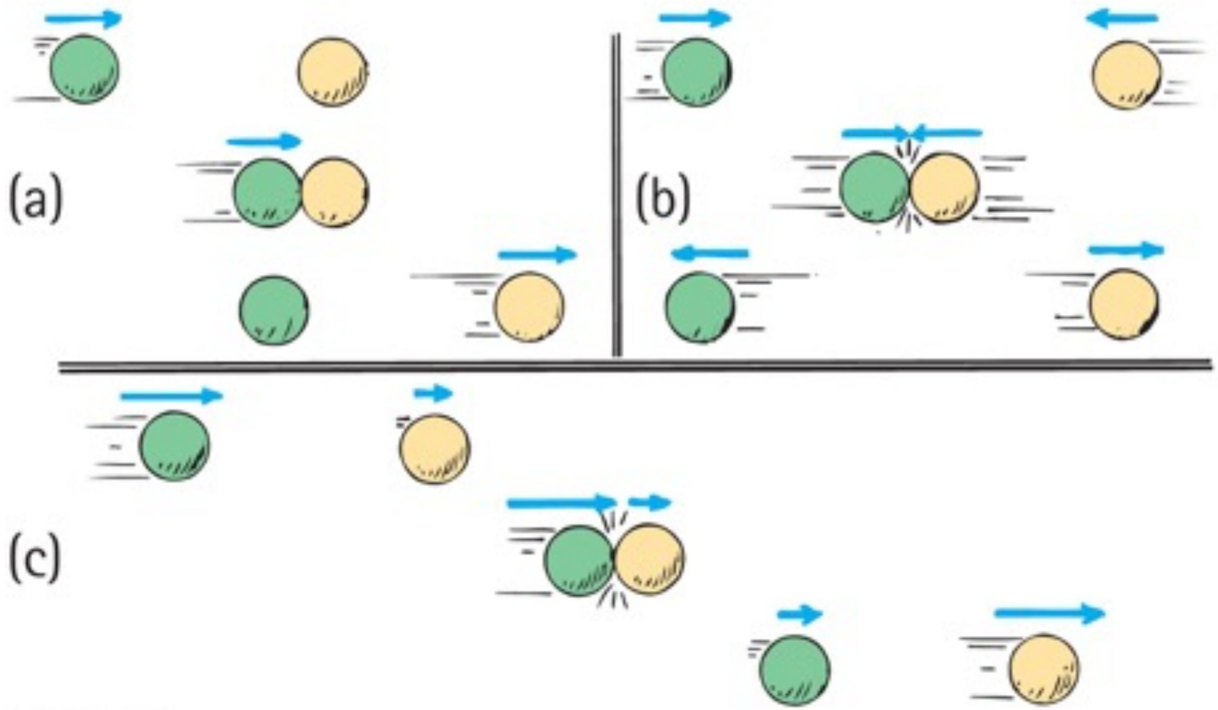
$$(\text{net } mv)_{\text{before}} = (\text{net } mv)_{\text{after}}$$

**In the absence of external forces, for all collisions momentum is conserved.**

# Collisions

**Elastic collision**

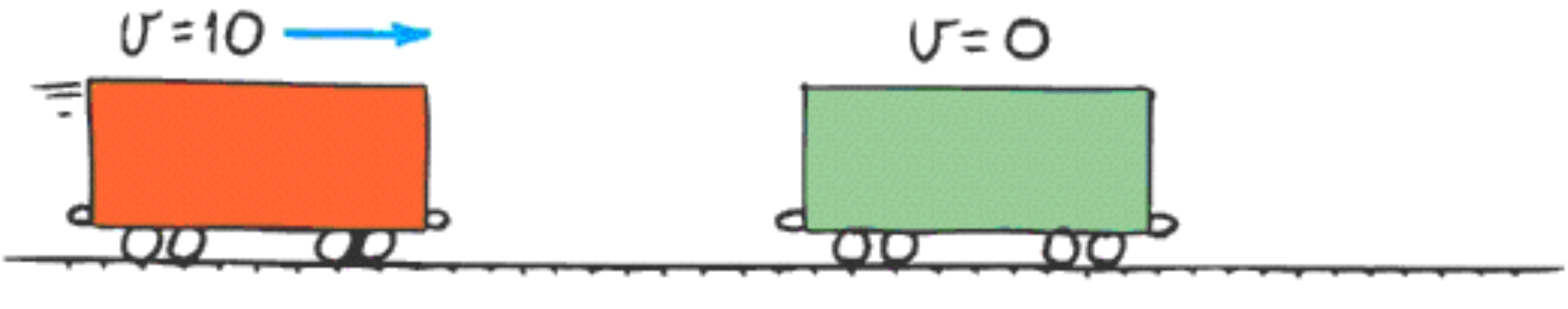
A. occurs when colliding objects rebound without lasting deformation or any generation of heat.



# Collisions

**Inelastic collision**

A. occurs when colliding objects result in deformation and/or the generation of heat.



# Collisions

Example of elastic collision:

single car moving at 10 m/s collides with another car of the same mass, *m*, at rest

From the conservation of momentum,

$(\text{net } mv)_{\text{before}} = (\text{net } mv)_{\text{after}}$

$(m \times 10)_{\text{before}} = (2m \times V)_{\text{after}}$

$V = 5$ m/s

Freight car A is moving toward identical freight car B that is at rest. When they collide, both freight cars couple together. Compared with the initial speed of freight car A, the speed of the coupled freight cars is

A. the same.

A. half.

B. twice.

C. None of the above.

Freight car A is moving toward identical freight car B that is at rest. When they collide, both freight cars couple together. Compared with the initial speed of freight car A, the speed of the coupled freight cars is

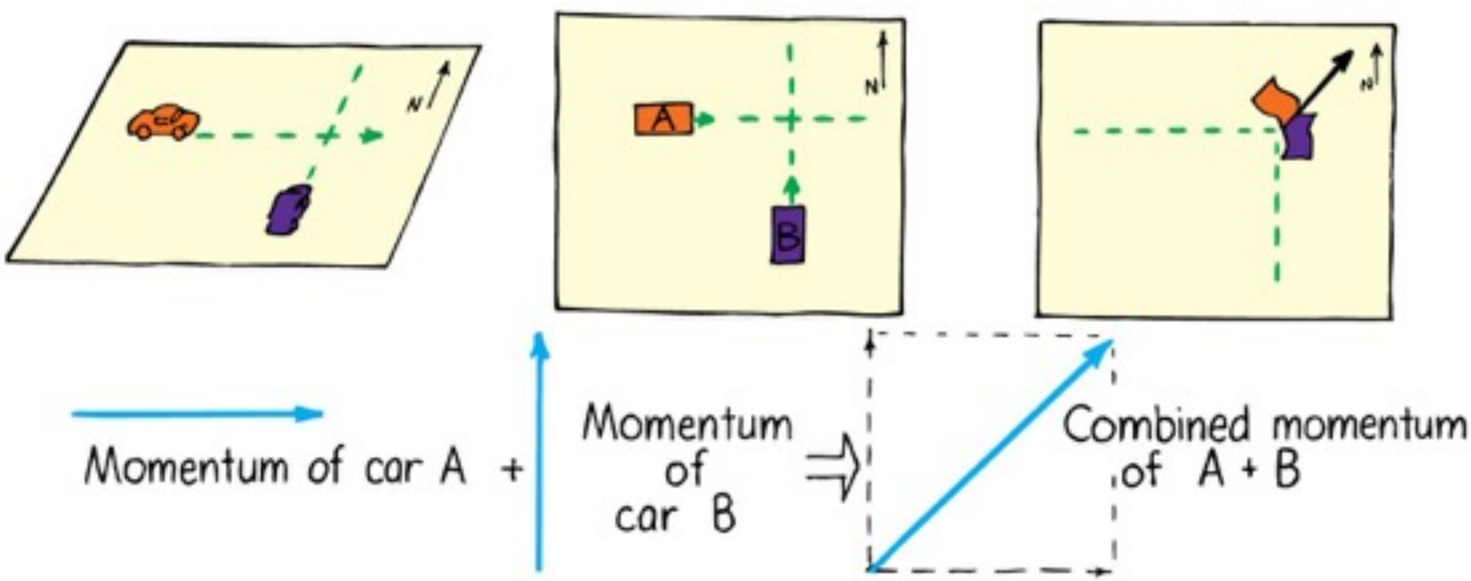
A. the same.
A. **half.**
B. twice.
C. None of the above.

*Explanation*:

After the collision, the mass of the moving freight cars has doubled. Can you see that their speed is half the initial velocity of freight car A?

# More Complicated Collisions

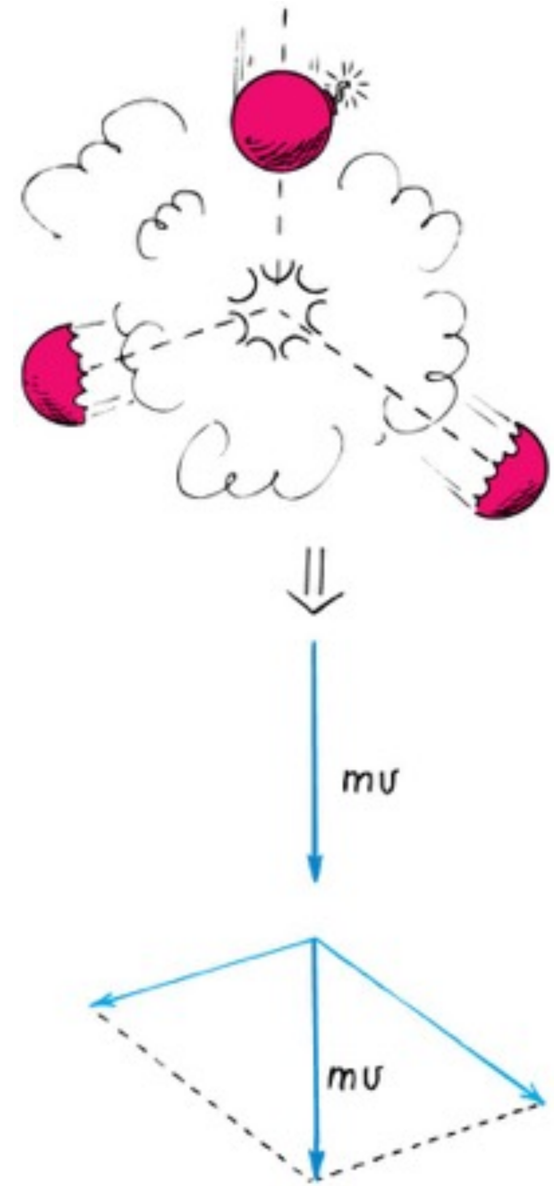
- Sometimes the colliding objects are not moving in the same straight line.
- In this case you create a parallelogram of the vectors describing each initial momentum to find the combined momentum.
- Example: collision of two cars at a corner



# More Complicated Collisions

Another example:

A firecracker exploding; the total momentum of the pieces after the explosion can be added vectorially to get the initial momentum of the firecracker before it exploded.



# Chapter 6 Problems

2. Joanne drives her car with a mass of 1000 kg at a speed of 20 m/s. Show that to bring her car to a halt in 10 s road friction must exert a force of 2000 N on the car.

$$I = F\,t = \Delta(mv)$$

# Chapter 6 Problems

2. Joanne drives her car with a mass of 1000 kg at a speed of 20 m/s. Show that to bring her car to a halt in 10 s road friction must exert a force of 2000 N on the car.

Since $F\ t = \Delta mv$, then $F = \Delta mv/t = (1000\text{ kg})(20\text{ m/s})/10\text{s}$

$$\mathbf{F = 2000\ kg\ m/s^2}$$

# Chapter 6 Problems

4. Judy (mass 40 kg), standing on slippery ice, catches her leaping dog (mass 15 kg) moving horizontally at 3.0 m/s. Show that the speed of Judy and her dog after the catch is 0.8 m/s.

   *Hint: momentum is conserved.*

# Chapter 6 Problems

4. Judy (mass 40 kg), standing on slippery ice, catches her leaping dog (mass 15 kg) moving horizontally at 3.0 m/s. Show that the speed of Judy and her dog after the catch is 0.8 m/s.

**momentum before = momentum after**

$m_{Judy} v_{Judy} + m_{dog} v_{dog} = (m_{Judy} + m_{dog}) v_{after}$

$v_{after} = m_{dog} v_{dog} / (m_{Judy} + m_{dog}) =$

$v_{after} = 15 \text{ kg } 3.0 \text{ m/s} / (40 \text{ kg} + 15 \text{ kg})$

$v_{after} = 45 \text{ kg m/s} / 55 \text{ kg} =$ **0.8 m/s**

# Chapter 6 Problems

6 A railroad diesel engine weighs four times as much as a freight car. If the diesel engine coasts at 5 km/h into a freight car that is initially at rest show that the speed of the coupled cars is 4 km/h.

# Homework

- Read Chapter 6 in Detail.
- Do Ranking 4
- Do Exercises 21, 48
- Do Problems 8, 10

**Homework due: June 06**