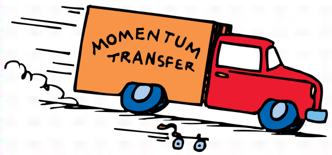


THE BIG IDEA

Momentum is conserved for all collisions as long as external forces don't interfere.

The concept of inertia was introduced and developed both in terms of objects at rest and objects in motion. In this chapter we are concerned only with the concept of inertia in motion—momentum.

8.1 Momentum

A moving object can have a large momentum if it has a large mass, a high speed, or both.

8.1 Momentum

It is harder to stop a large truck than a small car when both are moving at the same speed.

The truck has more momentum than the car. By momentum, we mean *inertia in motion.*

8.1 Momentum

Momentum is the mass of an object multiplied by its velocity.

momentum = mass × velocity

momentum = *mv*

When direction is not an important factor,

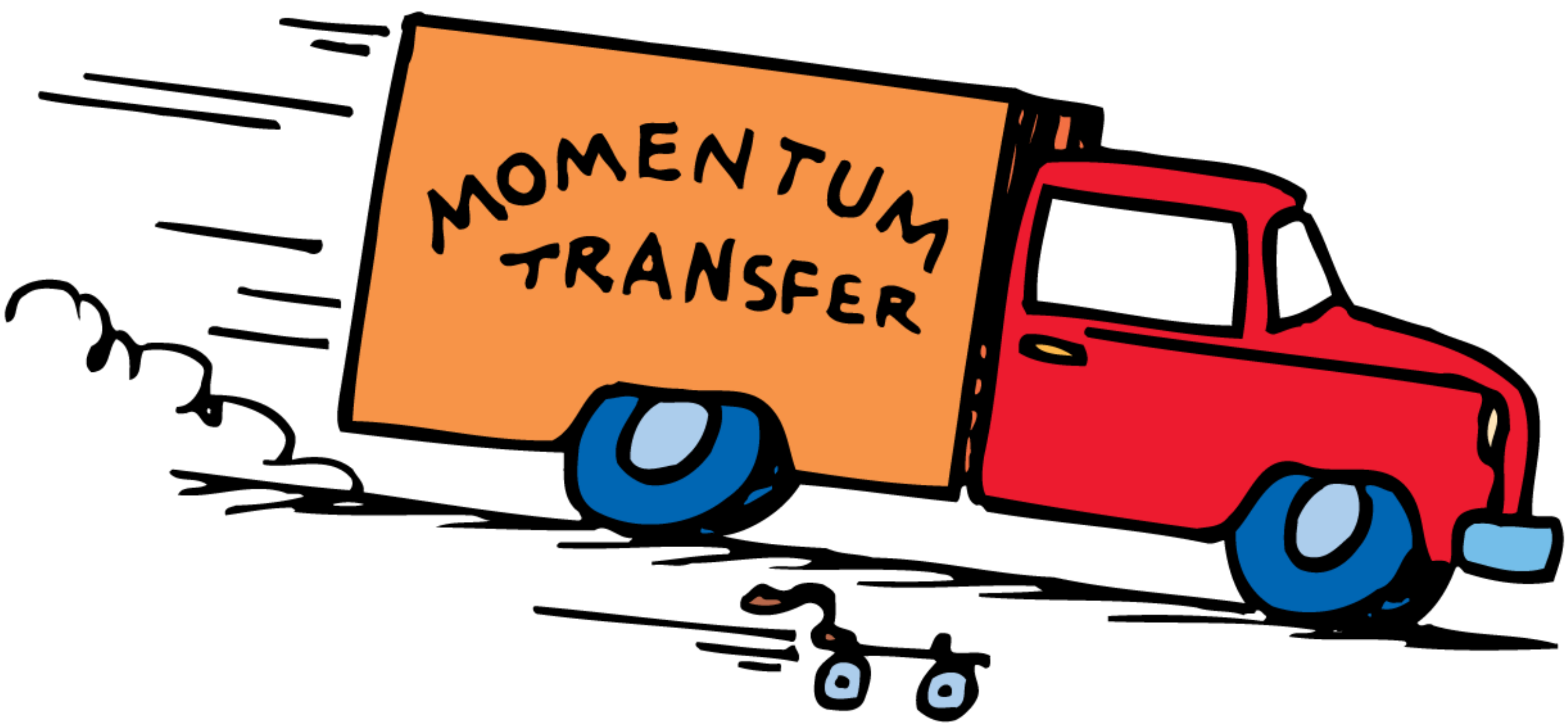
momentum = mass × speed

8.1 Momentum

- A moving truck has more momentum than a car moving at the same speed because the truck has more mass.
- A fast car can have more momentum than a slow truck.
- A truck at rest has no momentum at all.

8.1 Momentum

A truck rolling down a hill has more momentum than a roller skate with the same speed. But if the truck is at rest and the roller skate moves, then the skate has more momentum.



8.1 Momentum

think!

Can you think of a case where a roller skate and a truck would have the same momentum?

8.1 Momentum

think!

Can you think of a case where a roller skate and a truck would have the same momentum?

Answer: The roller skate and truck can have the same momentum if the speed of the roller skate is much greater than the speed of the truck. For example, a 1000-kg truck backing out of a driveway at 0.01 m/s has the same momentum as a 1-kg skate going 10 m/s. Both have momentum = 10 kg•m/s.

8.1 Momentum

CONCEPT CHECK What factors affect an object's momentum?

8.2 Impulse Changes Momentum

The change in momentum depends on the force that acts and the length of time it acts.

8.2 Impulse Changes Momentum

If the momentum of an object changes, either the mass or the velocity or both change.

The greater the force acting on an object, the greater its change in velocity and the greater its change in momentum.

8.2 Impulse Changes Momentum

Impulse

A force sustained for a long time produces more change in momentum than does the same force applied briefly.

Both force and time are important in changing an object's momentum.

8.2 Impulse Changes Momentum

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

8.2 Impulse Changes Momentum

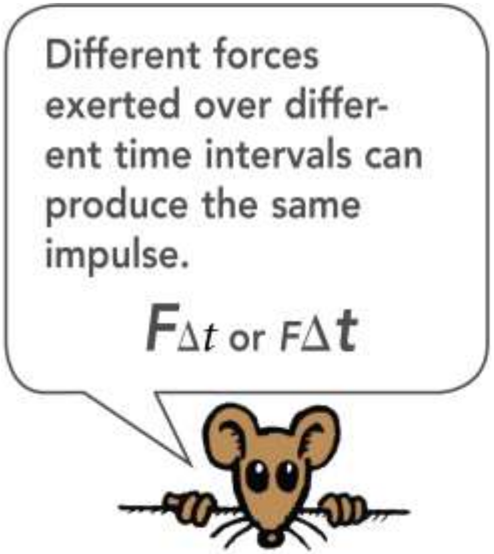
The quantity *force* × *time interval* is called **impulse.**

$$\text{impulse} = F \times t$$

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

$$\text{impulse} = \text{change in momentum}$$

$$Ft = \Delta(mv)$$



8.2 Impulse Changes Momentum

Increasing Momentum

To increase the momentum of an object, apply the greatest force possible for as long as possible.

A golfer teeing off and a baseball player trying for a home run do both of these things when they swing as hard as possible and follow through with their swing.

8.2 Impulse Changes Momentum

The force of impact on a golf ball varies throughout the duration of impact.

8.2 Impulse Changes Momentum

The forces involved in impulses usually vary from instant to instant.

- A golf club that strikes a golf ball exerts zero force on the ball until it comes in contact with it.
- The force increases rapidly as the ball becomes distorted.
- The force diminishes as the ball comes up to speed and returns to its original shape.
- We can use the *average* force to solve for the impulse on an object.

8.2 Impulse Changes Momentum

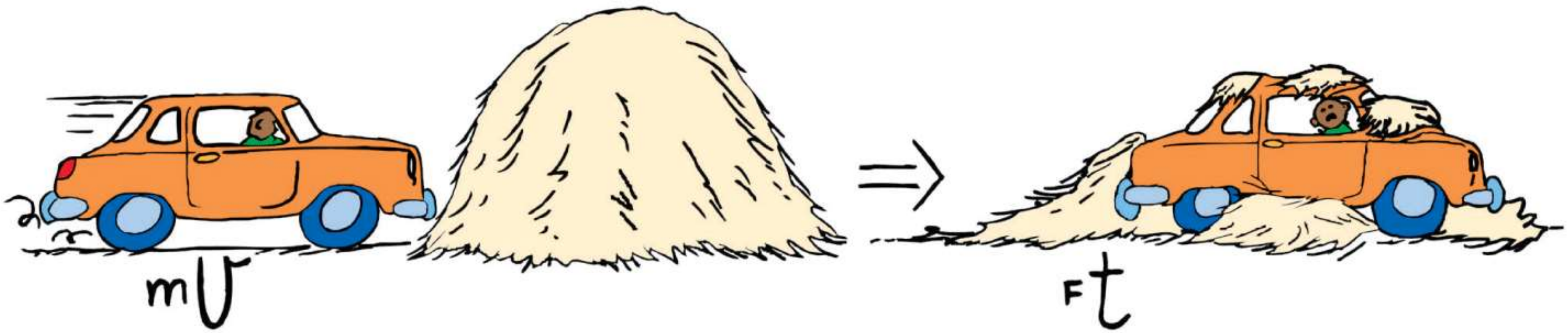
Decreasing Momentum

If you were in a car that was out of control and had to choose between hitting a haystack or a concrete wall, you would choose the haystack.

Physics helps you to understand *why* hitting a soft object is entirely different from hitting a hard one.

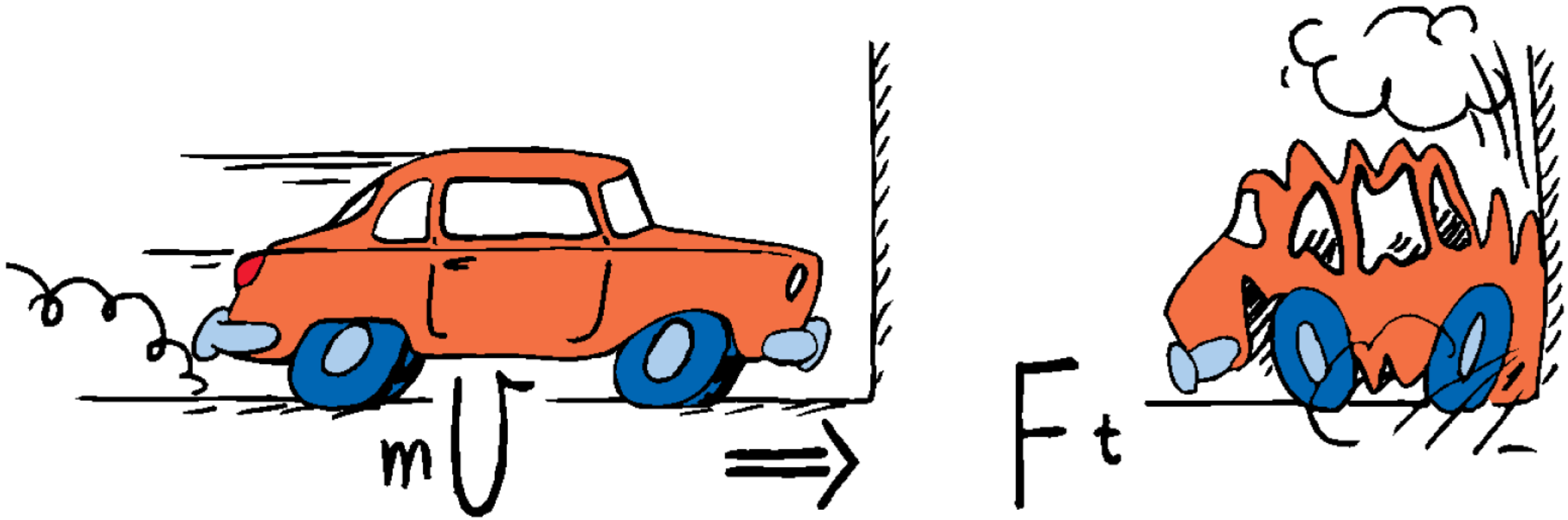
8.2 Impulse Changes Momentum

If the change in momentum occurs over a long time, the force of impact is small.



8.2 Impulse Changes Momentum

If the change in momentum occurs over a short time, the force of impact is large.



8.2 Impulse Changes Momentum

When hitting either the wall or the haystack and coming to a stop, the momentum is decreased by the same impulse.

- The same impulse does not mean the same amount of force or the same amount of time.
- It means the same *product* of force and time.
- To keep the force small, we extend the time.

8.2 Impulse Changes Momentum

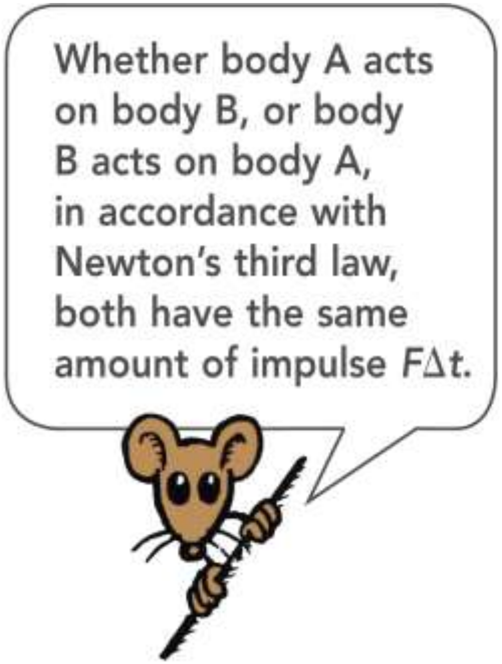
When you extend the time, you reduce the force.

- A padded dashboard in a car is safer than a rigid metal one.
- Airbags save lives.
- To catch a fast-moving ball, extend your hand forward and move it backward after making contact with the ball.

8.2 Impulse Changes Momentum

When you jump down to the ground, bend your knees when your feet make contact with the ground to extend the time during which your momentum decreases.

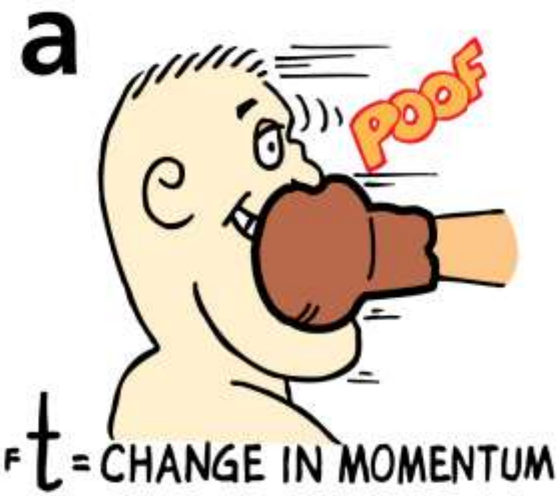
A wrestler thrown to the floor extends his time of hitting the mat, spreading the impulse into a series of smaller ones as his foot, knee, hip, ribs, and shoulder successively hit the mat.



8.2 Impulse Changes Momentum

The impulse provided by a boxer's jaw counteracts the momentum of the punch.

a. The boxer moves away from the punch.

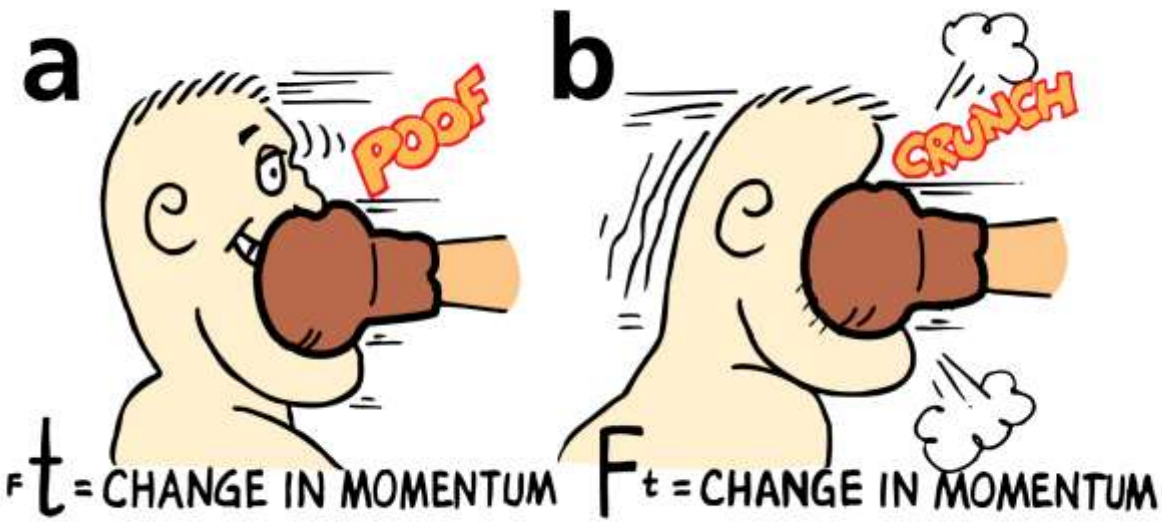


8.2 Impulse Changes Momentum

The impulse provided by a boxer's jaw counteracts the momentum of the punch.

a. The boxer moves away from the punch.

b. The boxer moves toward the punch. Ouch!



8.2 Impulse Changes Momentum

A glass dish is more likely to survive if it is dropped on a carpet rather than a sidewalk. The carpet has more “give.”

Since time is longer hitting the carpet than hitting the sidewalk, a smaller force results.

The shorter time hitting the sidewalk results in a greater stopping force.

8.2 Impulse Changes Momentum

The safety net used by circus acrobats is a good example of how to achieve the impulse needed for a safe landing.

The safety net reduces the stopping force on a fallen acrobat by substantially increasing the time interval of the contact.

8.2 Impulse Changes Momentum

think!

When a dish falls, will the impulse be less if it lands on a carpet than if it lands on a hard floor?

8.2 Impulse Changes Momentum

think!

When a dish falls, will the impulse be less if it lands on a carpet than if it lands on a hard floor?

Answer: No. The impulse would be the same for either surface because the same momentum change occurs for each. It is the *force* that is less for the impulse on the carpet because of the greater time of momentum change.

8.2 Impulse Changes Momentum

think!

If a boxer is able to make the contact time five times longer by "riding" with the punch, how much will the force of the punch impact be reduced?

8.2 Impulse Changes Momentum

think!

If a boxer is able to make the contact time five times longer by “riding” with the punch, how much will the force of the punch impact be reduced?

Answer: Since the time of impact increases five times, the force of impact will be reduced five times.

8.2 Impulse Changes Momentum

CONCEPT CHECK

What factors affect how much an object's momentum changes?

8.3 Bouncing

The impulse required to bring an object to a stop and then to “throw it back again” is greater than the impulse required merely to bring the object to a stop.

8.3 Bouncing

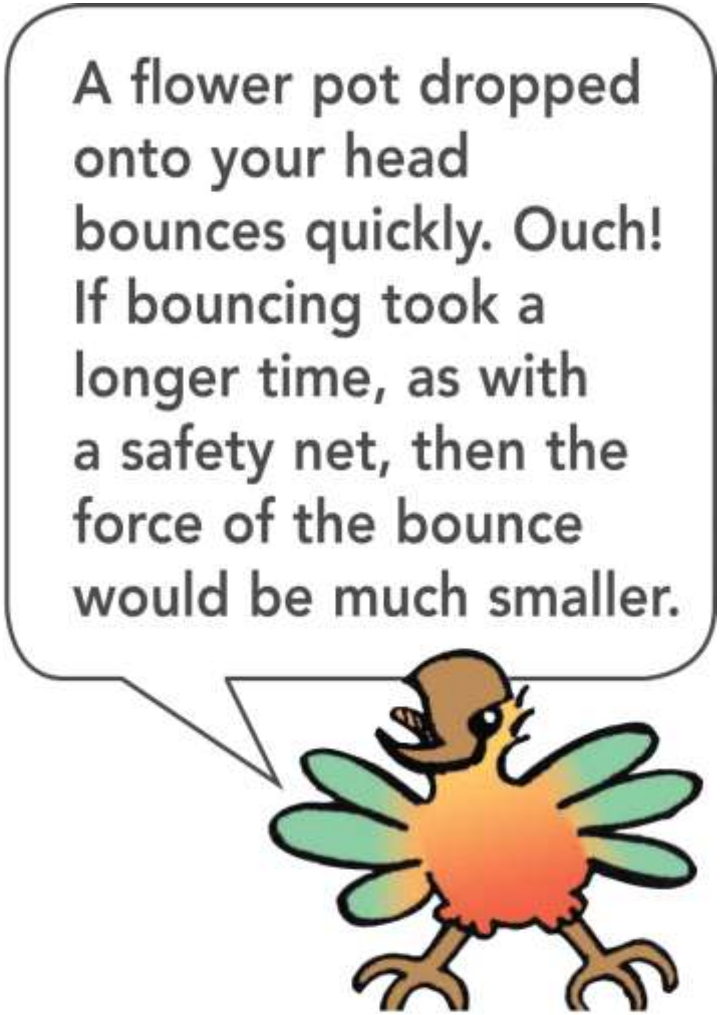
Suppose you catch a falling pot with your hands.

- You provide an impulse to reduce its momentum to zero.
- If you throw the pot upward again, you have to provide additional impulse.

8.3 Bouncing

If the flower pot falls from a shelf onto your head, you may be in trouble.

If it bounces from your head, you may be in more serious trouble because impulses are greater when an object bounces. The increased impulse is supplied by your head if the pot bounces.

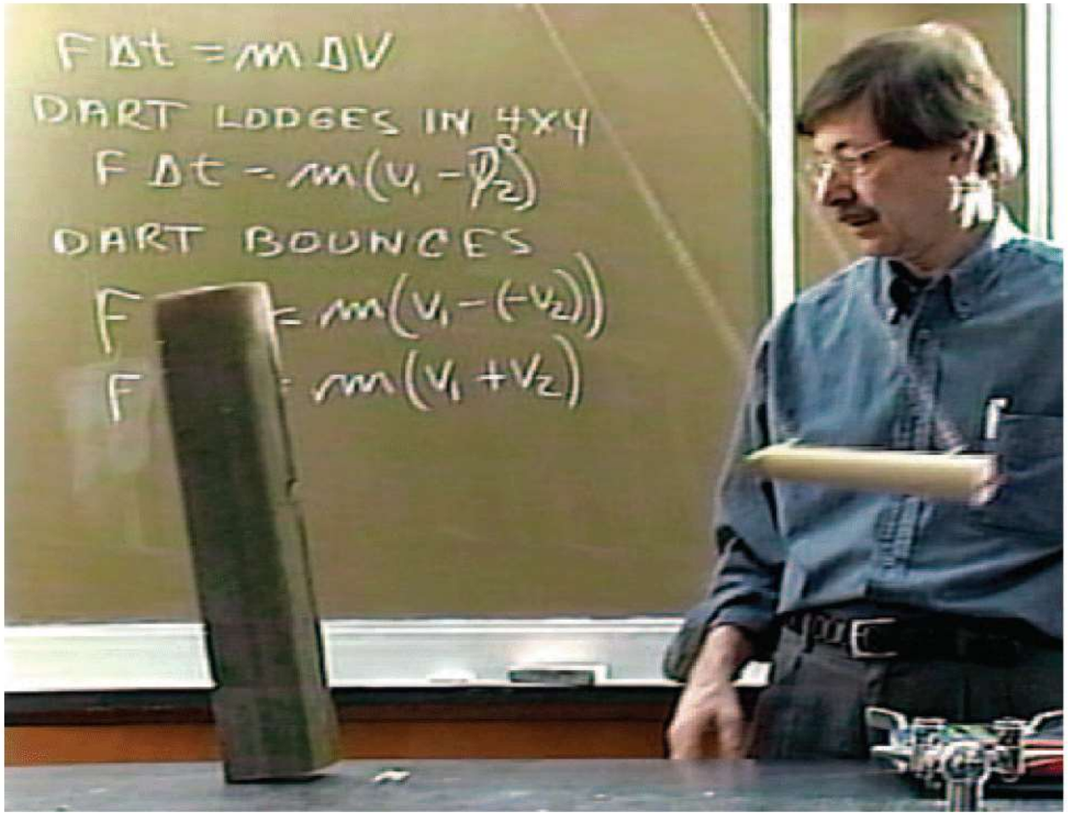


8.3 Bouncing

Cassy imparts a large impulse to the bricks in a short time and produces considerable force. Her hand bounces back, yielding as much as twice the impulse to the bricks.

8.3 Bouncing

The block topples when the swinging dart bounces from it. Without the rubber head of the dart, it doesn't bounce when it hits the block and no toppling occurs.



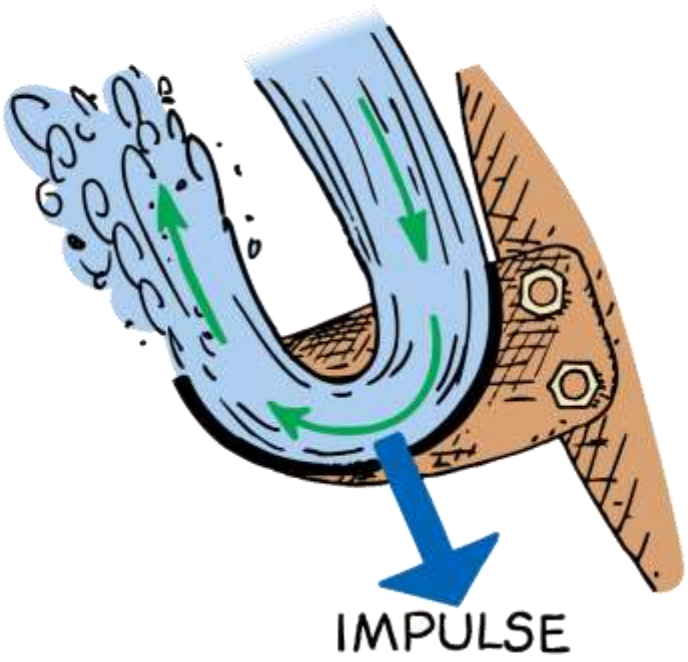
8.3 Bouncing

The waterwheels used in gold mining operations during the California Gold Rush were not very effective.

Lester A. Pelton designed a curve-shaped paddle that caused the incoming water to make a U-turn upon impact. The water "bounced," increasing the impulse exerted on the waterwheel.

8.3 Bouncing

The curved blades of the Pelton Wheel cause water to bounce and make a U-turn, producing a large impulse that turns the wheel.



8.3 Bouncing

CONCEPT CHECK

How does the impulse of a bounce compare to stopping only?

8.4 Conservation of Momentum

The law of conservation of momentum states that, in the absence of an external force, the momentum of a system remains unchanged.

8.4 Conservation of Momentum

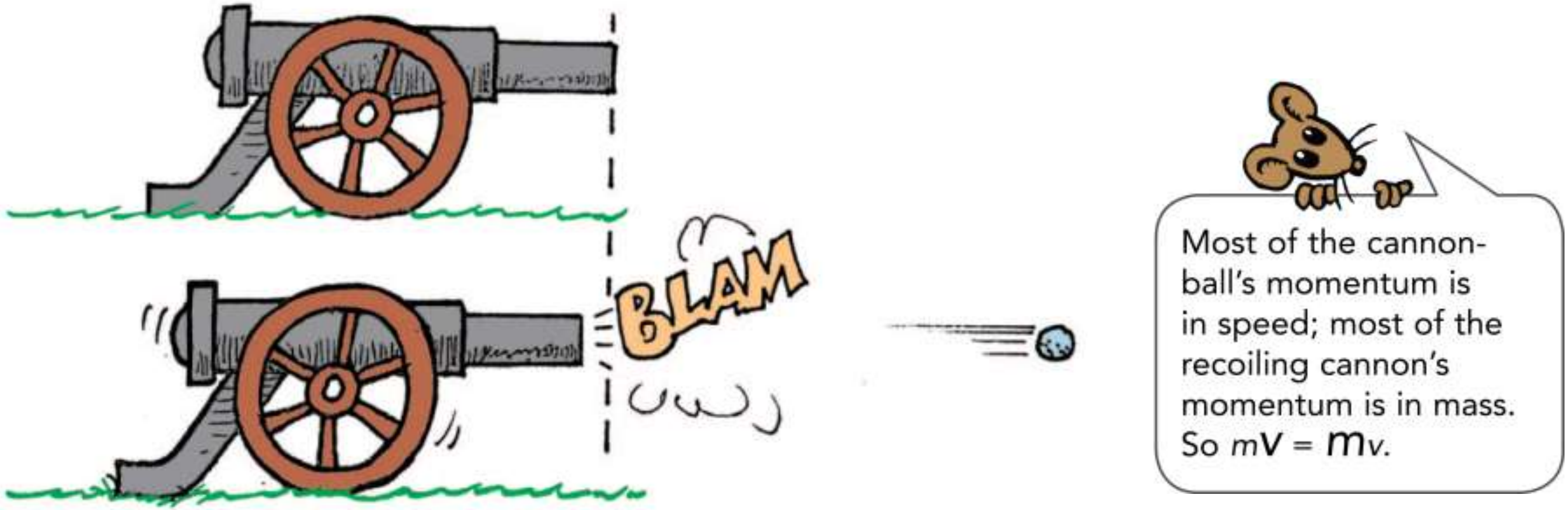
The force or impulse that changes momentum must be exerted on the object by something outside the object.

- Molecular forces within a basketball have no effect on the momentum of the basketball.
- A push against the dashboard from inside does not affect the momentum of a car.

These are internal forces. They come in balanced pairs that cancel within the object.

8.4 Conservation of Momentum

The momentum before firing is zero. After firing, the net momentum is still zero because the momentum of the cannon is equal and opposite to the momentum of the cannonball.



8.4 Conservation of Momentum

The force on the cannonball inside the cannon barrel is equal and opposite to the force causing the cannon to recoil. The action and reaction forces are internal to the system so they don't change the momentum of the cannon-cannonball system.

- Before the firing, the momentum is zero.
- After the firing, the net momentum is *still* zero.
- Net momentum is neither gained nor lost.

8.4 Conservation of Momentum

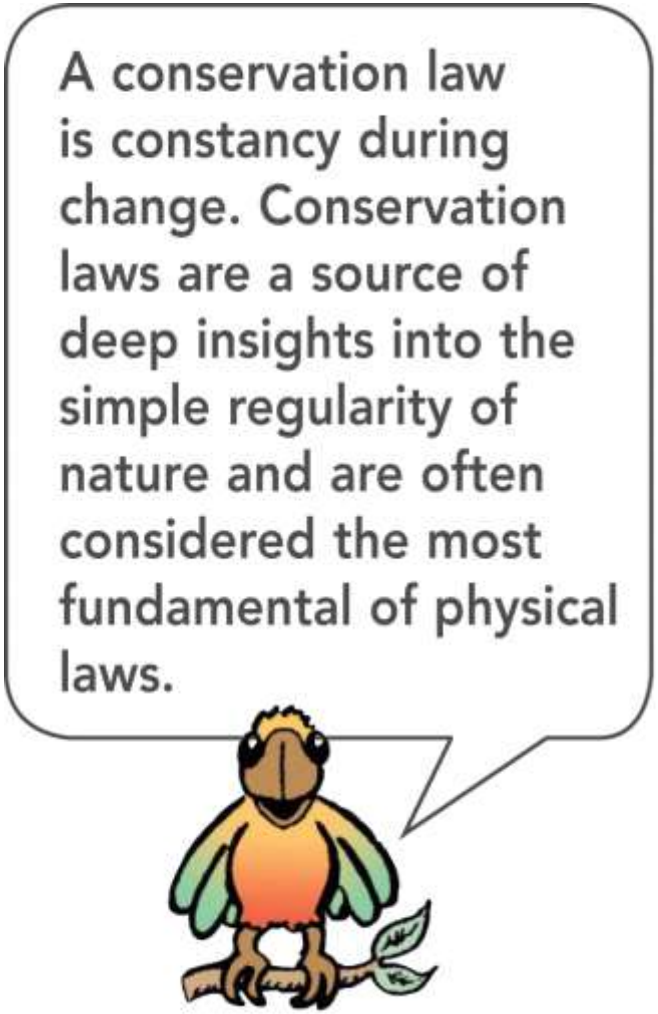
Momentum has both direction and magnitude. It is a *vector quantity.*

- The cannonball gains momentum and the recoiling cannon gains momentum in the opposite direction.
- The cannon-cannonball *system* gains none.
- The momenta of the cannonball and the cannon are equal in magnitude and opposite in direction.
- No net force acts on the system so there is no net impulse on the system and there is no net change in the momentum.

8.4 Conservation of Momentum

In every case, the momentum of a system cannot change unless it is acted on by external forces.

When any quantity in physics does not change, we say it is *conserved.*



8.4 Conservation of Momentum

The **law of conservation of momentum** describes the momentum of a system:

If a system undergoes changes wherein all forces are internal, the net momentum of the system before and after the event is the same. Examples are:

- atomic nuclei undergoing radioactive decay,
- cars colliding, and
- stars exploding.

8.4 Conservation of Momentum

think!

Newton's second law states that if no net force is exerted on a system, no acceleration occurs. Does it follow that no change in momentum occurs?

8.4 Conservation of Momentum

think!

Newton's second law states that if no net force is exerted on a system, no acceleration occurs. Does it follow that no change in momentum occurs?

Answer: Yes, because no acceleration means that no change occurs in velocity or in momentum (mass × velocity). Another line of reasoning is simply that no net force means there is no net impulse and thus no change in momentum.

8.4 Conservation of Momentum

CONCEPT CHECK

What does the law of conservation of momentum state?

8.5 Collisions

Whenever objects collide in the absence of external forces, the net momentum of the objects before the collision equals the net momentum of the objects after the collision.

8.5 Collisions

The collision of objects clearly shows the conservation of momentum.

$$\text{net momentum}_{\text{before collision}} = \text{net momentum}_{\text{after collision}}$$

8.5 Collisions

Elastic Collisions

When a moving billiard ball collides head-on with a ball at rest, the first ball comes to rest and the second ball moves away with a velocity equal to the initial velocity of the first ball.

Momentum is transferred from the first ball to the second ball.

8.5 Collisions

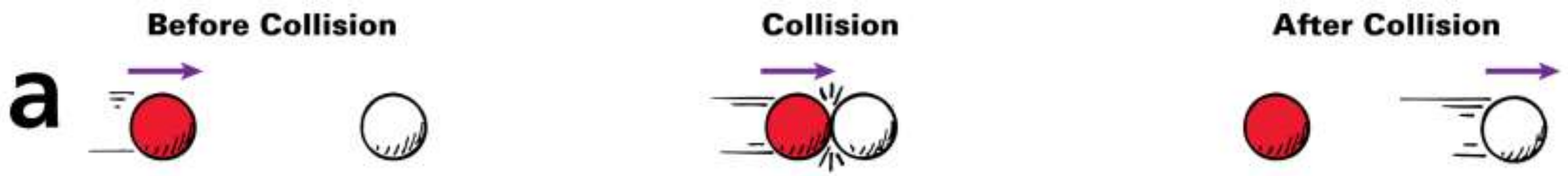
When objects collide without being permanently deformed and without generating heat, the collision is an **elastic collision.**

Colliding objects bounce perfectly in perfect elastic collisions.

The sum of the momentum vectors is the same before and after each collision.

8.5 Collisions

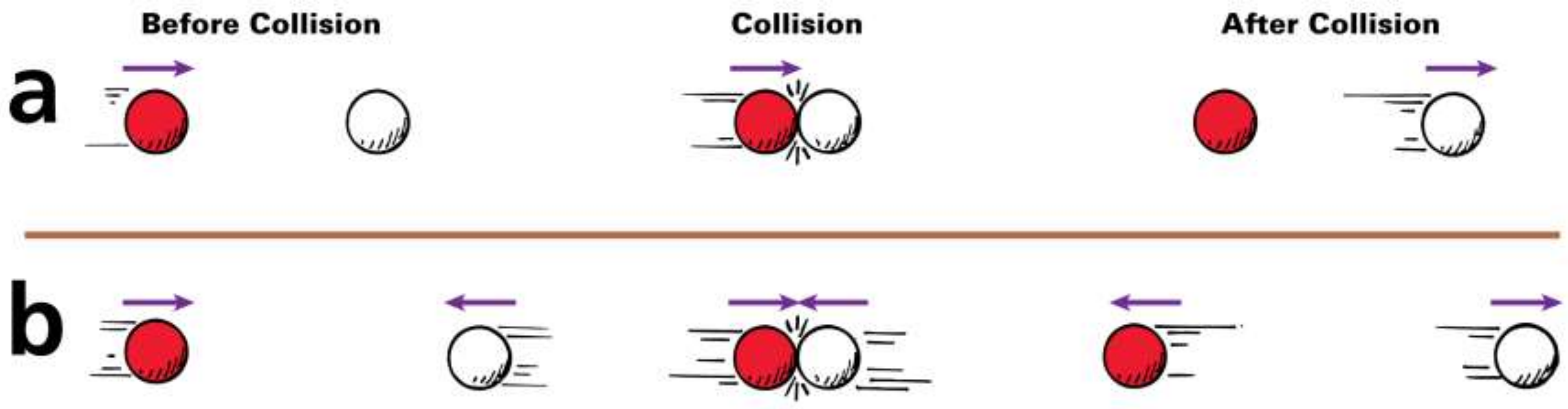
a. A moving ball strikes a ball at rest.



8.5 Collisions

a. A moving ball strikes a ball at rest.

b. Two moving balls collide head-on.

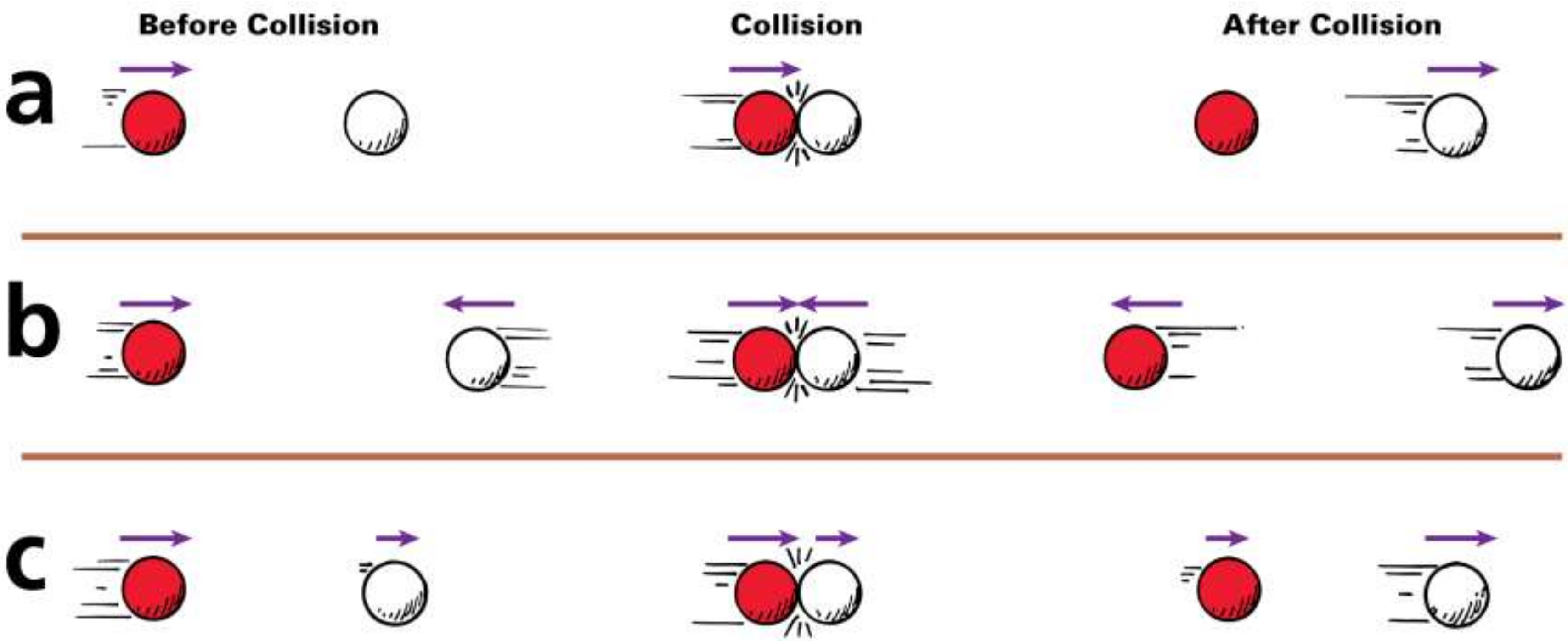


8.5 Collisions

a. A moving ball strikes a ball at rest.

b. Two moving balls collide head-on.

c. Two balls moving in the same direction collide.



8.5 Collisions

Inelastic Collisions

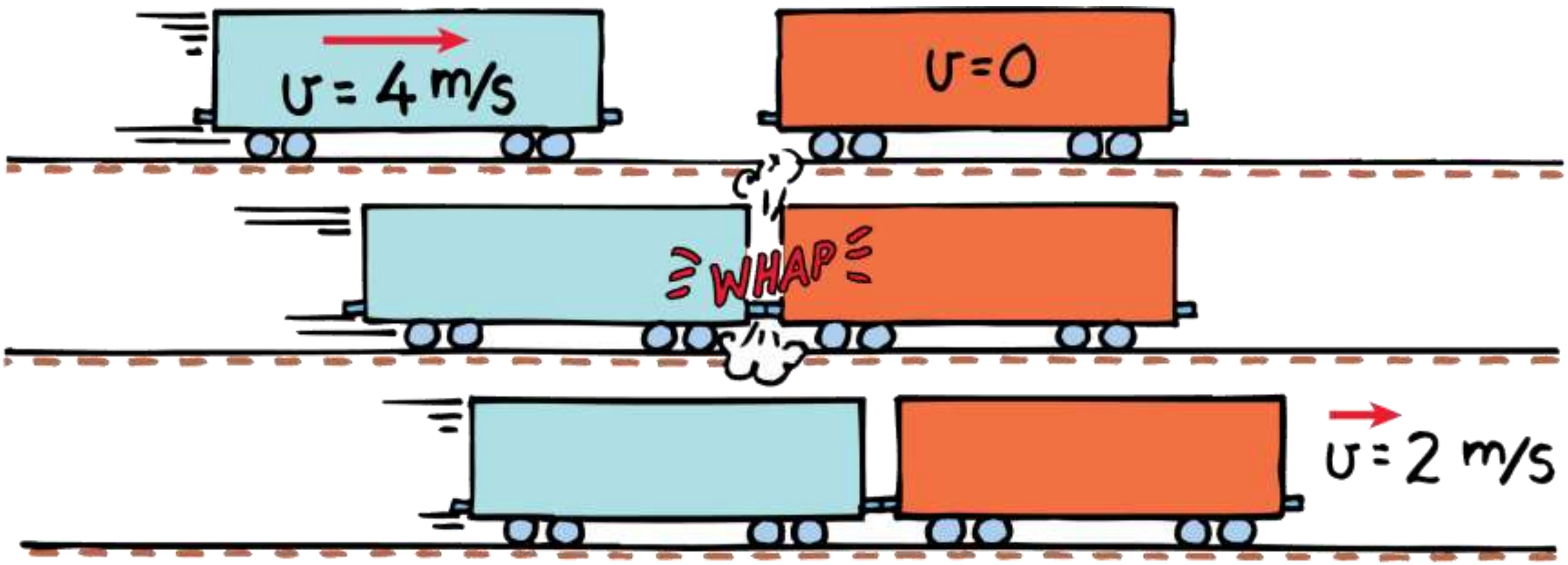
A collision in which the colliding objects become distorted and generate heat during the collision is an **inelastic collision.**

Momentum conservation holds true even in inelastic collisions.

Whenever colliding objects become tangled or couple together, a totally inelastic collision occurs.

8.5 Collisions

In an inelastic collision between two freight cars, the momentum of the freight car on the left is shared with the freight car on the right.



8.5 Collisions

The freight cars are of equal mass *m,* and one car moves at 4 m/s toward the other car that is at rest.

net momentum $_{\text{before collision}}$ = net momentum $_{\text{after collision}}$

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

$(m)(4 \text{ m/s}) + (m)(0 \text{ m/s}) = (2m)(v_{\text{after}})$

8.5 Collisions

Twice as much mass is moving after the collision, so the velocity, v_{after}, must be one half of 4 m/s.

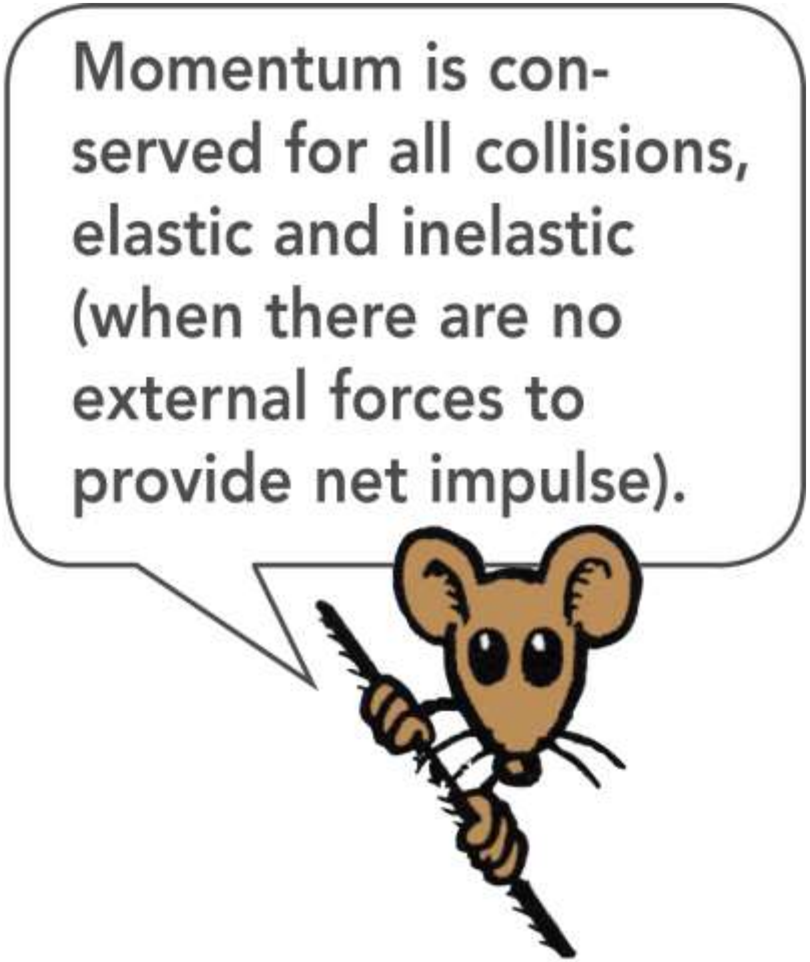
v_{after} = 2 m/s in the same direction as the velocity before the collision, v_{before}.

8.5 Collisions

The initial momentum is shared by both cars without loss or gain.

Momentum is conserved.

External forces are usually negligible during the collision, so the net momentum does not change during collision.



8.5 Collisions

External forces may have an effect after the collision:

- Billiard balls encounter friction with the table and the air.
- After a collision of two trucks, the combined wreck slides along the pavement and friction decreases its momentum.
- Two space vehicles docking in orbit have the same net momentum just before and just after contact. Since there is no air resistance in space, the combined momentum is then changed only by gravity.

8.5 Collisions

Perfectly elastic collisions are not common in the everyday world. Drop a ball and after it bounces from the floor, both the ball and the floor are a bit warmer.

At the microscopic level, however, perfectly elastic collisions are commonplace. For example, electrically charged particles bounce off one another without generating heat; they don’t even touch in the classic sense of the word.

8.5 Collisions

An air track nicely demonstrates conservation of momentum. Many small air jets provide a nearly frictionless cushion of air for the gliders to slide on.

8.5 Collisions

think!

One glider is loaded so it has three times the mass of another glider. The loaded glider is initially at rest. The unloaded glider collides with the loaded glider and the two gliders stick together. Describe the motion of the gliders after the collision.

8.5 Collisions

think!

One glider is loaded so it has three times the mass of another glider. The loaded glider is initially at rest. The unloaded glider collides with the loaded glider and the two gliders stick together. Describe the motion of the gliders after the collision.

Answer: The mass of the stuck-together gliders is four times that of the unloaded glider. The velocity of the stuck-together gliders is one fourth of the unloaded glider's velocity before collision. This velocity is in the same direction as before, since the direction as well as the amount of momentum is conserved.

8.5 Collisions

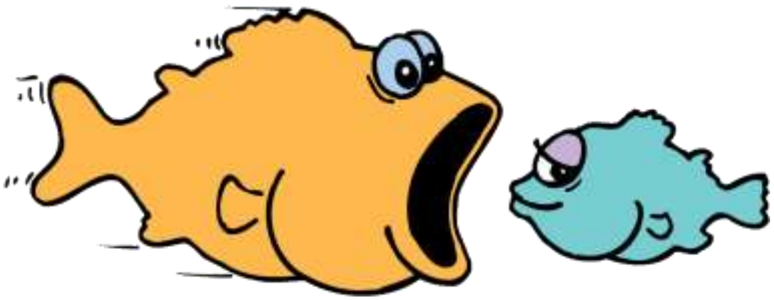
do the math!

Consider a 6-kg fish that swims toward and swallows a 2-kg fish that is at rest. If the larger fish swims at 1 m/s, what is its velocity immediately after lunch?

8.5 Collisions

do the math!

Consider a 6-kg fish that swims toward and swallows a 2-kg fish that is at rest. If the larger fish swims at 1 m/s, what is its velocity immediately after lunch?



Momentum is conserved from the instant before lunch until the instant after (in so brief an interval, water resistance does not have time to change the momentum).

8.5 Collisions

do the math!

$$\text{net momentum}_{\text{before lunch}} = \text{net momentum}_{\text{after lunch}}$$

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

$$(6\ \text{kg})(1\ \text{m/s}) + (2\ \text{kg})(0\ \text{m/s}) = (6\ \text{kg} + 2\ \text{kg})(v_{\text{after}})$$

$$6\ \text{kg}\cdot\text{m/s} = (8\ \text{kg})(v_{\text{after}})$$

$$v_{\text{after}} = \frac{6\ \text{kg}\cdot\text{m/s}}{8\ \text{kg}} = \frac{3}{4}\ \text{m/s}$$

8.5 Collisions

do the math!

Suppose the small fish is not at rest but is swimming toward the large fish at 2 m/s.

8.5 Collisions

do the math!

Suppose the small fish is not at rest but is swimming toward the large fish at 2 m/s.

If we consider the direction of the large fish as positive, then the velocity of the small fish is –2 m/s.

8.5 Collisions

do the math!

The negative momentum of the small fish slows the large fish.

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

$$(6\text{ kg})(1\text{ m/s}) + (2\text{ kg})(-2\text{ m/s}) = (6\text{ kg} + 2\text{ kg})(v_{\text{after}})$$

$$(6\text{ kg}\cdot\text{m/s}) + (-4\text{ kg}\cdot\text{m/s}) = (8\text{ kg})(v_{\text{after}})$$

$$v_{\text{after}} = \frac{2\text{ kg}\cdot\text{m/s}}{8\text{ kg}} = \frac{1}{4}\text{ m/s}$$

8.5 Collisions

do the math!

If the small fish were swimming at –3 m/s, then both fish would have equal and opposite momenta.

Zero momentum before lunch would equal zero momentum after lunch, and both fish would come to a halt.

8.5 Collisions

do the math!

Suppose the small fish swims at –4 m/s.

The minus sign tells us that after lunch the two-fish system moves in a direction opposite to the large fish's direction before lunch.

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

$$(6 \text{ kg})(1 \text{ m/s}) + (2 \text{ kg})(-4 \text{ m/s}) + (6 \text{ kg} + 2 \text{ kg})(v_{\text{after}})$$

$$(6 \text{ kg}\cdot\text{m/s}) + (-8 \text{ kg}\cdot\text{m/s}) = (8 \text{ kg})(v_{\text{after}})$$

$$v_{\text{after}} = \frac{-2 \text{ kg}\cdot\text{m/s}}{8 \text{ kg}} = -\frac{1}{4} \text{ m/s}$$

8.5 Collisions

CONCEPT CHECK

How does conservation of momentum apply to collisions?

8.6 Momentum Vectors

The vector sum of the momenta is the same before and after a collision.

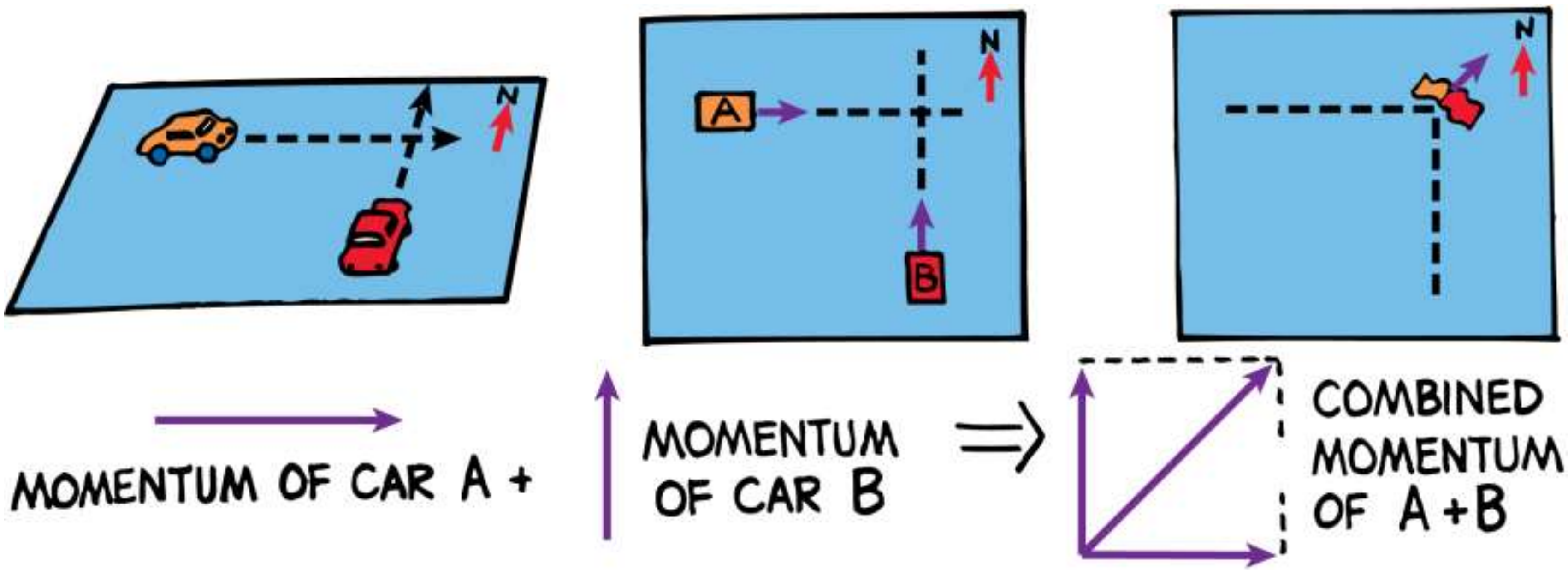
8.6 Momentum Vectors

Momentum is conserved even when interacting objects don't move along the same straight line. To analyze momentum in any direction, we use the vector techniques we've previously learned.

We'll look at momentum conservation involving angles by considering three examples.

8.6 Momentum Vectors

Momentum is a vector quantity. The momentum of the wreck is equal to the vector sum of the momenta of car A and car B before the collision.



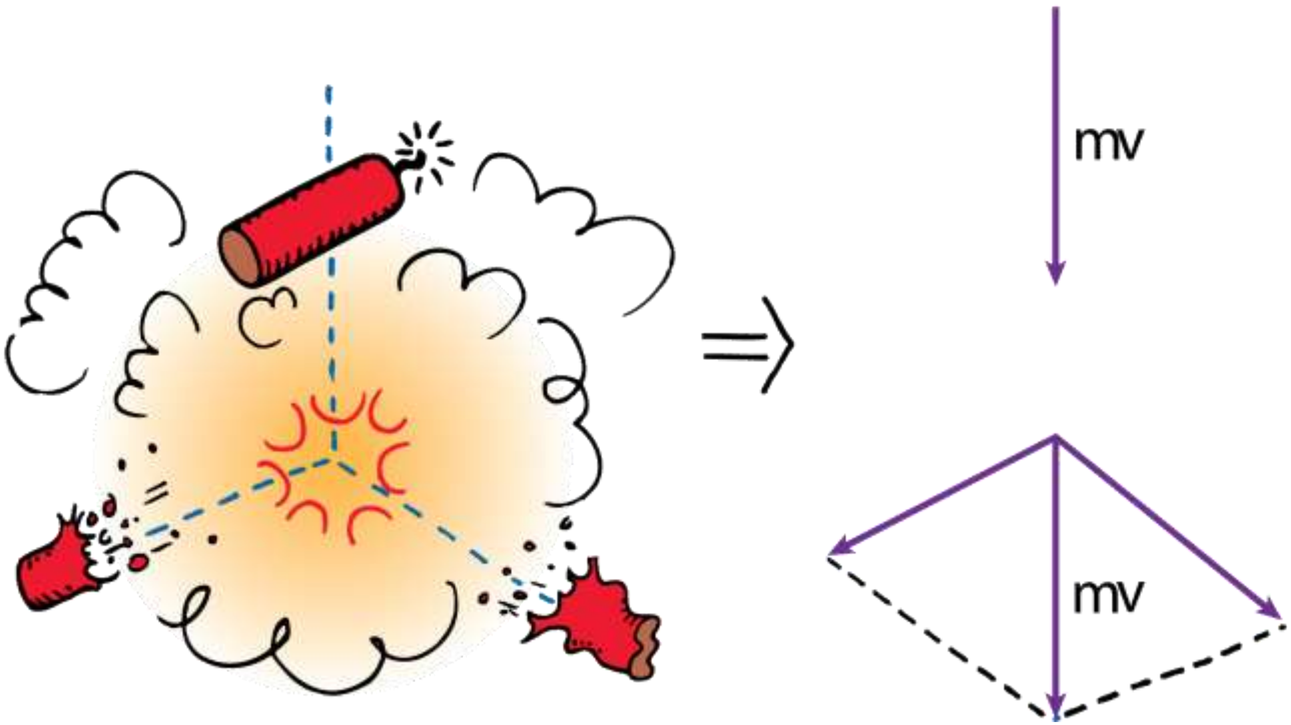
8.6 Momentum Vectors

The momentum of car A is directed due east and that of car B is directed due north.

If their momenta are equal in magnitude, after colliding their combined momentum will be in a northeast direction with a magnitude $\sqrt{2}$ times the momentum either vehicle had before the collision.

8.6 Momentum Vectors

When the firecracker bursts, the vector sum of the momenta of its fragments add up to the firecracker's momentum just before bursting.



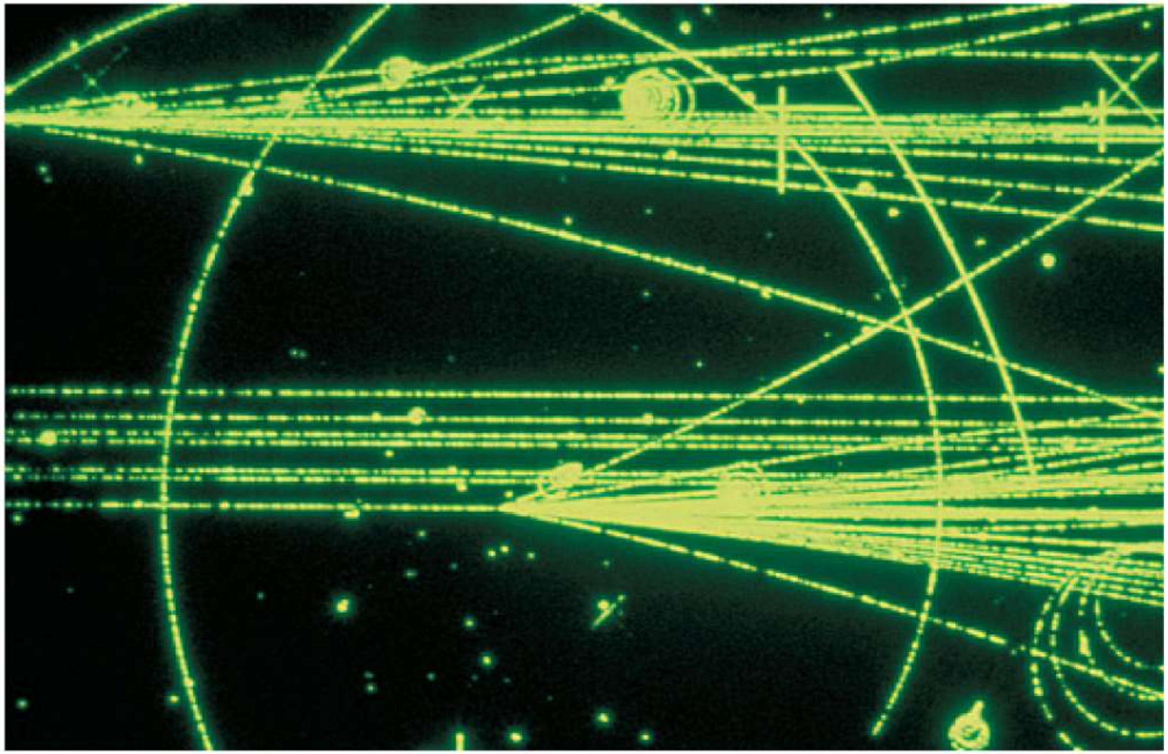
8.6 Momentum Vectors

A falling firecracker explodes into two pieces.

The momenta of the fragments combine by vector rules to equal the original momentum of the falling firecracker.

8.6 Momentum Vectors

Momentum is conserved for the high-speed elementary particles, as shown by the tracks they leave in a bubble chamber.



8.6 Momentum Vectors

Subatomic particles make tracks in a bubble chamber.

The mass of these particles can be computed by applying both the conservation of momentum and conservation of energy laws.

The conservation laws are extremely useful to experimenters in the atomic and subatomic realms.

8.6 Momentum Vectors

CONCEPT CHECK

What is true about the vector sum of momenta in a collision?

Assessment Questions

1. When the speed of an object is doubled, its momentum
   a. remains unchanged in accord with the conservation of momentum.
   b. doubles.
   c. quadruples.
   d. decreases.

Assessment Questions

1. When the speed of an object is doubled, its momentum
   a. remains unchanged in accord with the conservation of momentum.
   b. doubles.
   c. quadruples.
   d. decreases.

Answer: B

Assessment Questions

2. The impulse-momentum relationship is a direct result of Newton's
    a. first law.
    b. second law.
    c. third law.
    d. law of gravity.

Assessment Questions

2. The impulse-momentum relationship is a direct result of Newton's
   a. first law.
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   d. law of gravity.

Answer: B

Assessment Questions

3. When a falling object bounces, as it hits the ground its change in momentum and the impulse on it is
   a. less than for stopping.
   b. greater than for stopping.
   c. the same as it is for stopping.
   d. the same as it was when dropped.

Assessment Questions

3. When a falling object bounces, as it hits the ground its change in momentum and the impulse on it is
   a. less than for stopping.
   b. greater than for stopping.
   c. the same as it is for stopping.
   d. the same as it was when dropped.

Answer: B

Assessment Questions

4. On roller blades you horizontally toss a ball away from you. The mass of the ball is one tenth your mass. Compared with the speed you give to the ball, your recoil speed will ideally be
   a. one tenth as much.
   b. the same.
   c. ten times as much.
   d. 100 times as much.

Assessment Questions

4. On roller blades you horizontally toss a ball away from you. The mass of the ball is one tenth your mass. Compared with the speed you give to the ball, your recoil speed will ideally be
   a. one tenth as much.
   b. the same.
   c. ten times as much.
   d. 100 times as much.

Answer: A

Assessment Questions

5. A big fish swims upon and swallows a small fish at rest. After lunch, the big fish has less
   a. speed.
   b. momentum.
   c. both of these
   d. none of these

Assessment Questions

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   a. speed.
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Answer: A

Assessment Questions

6. A falling firecracker bursts into two pieces. Compared with the momentum of the firecracker when it bursts, the two pieces

   a. combined have the same momentum.

   b. each have half as much momentum.

   c. have more momentum.

   d. may or may not have more momentum.

Assessment Questions

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Answer: A