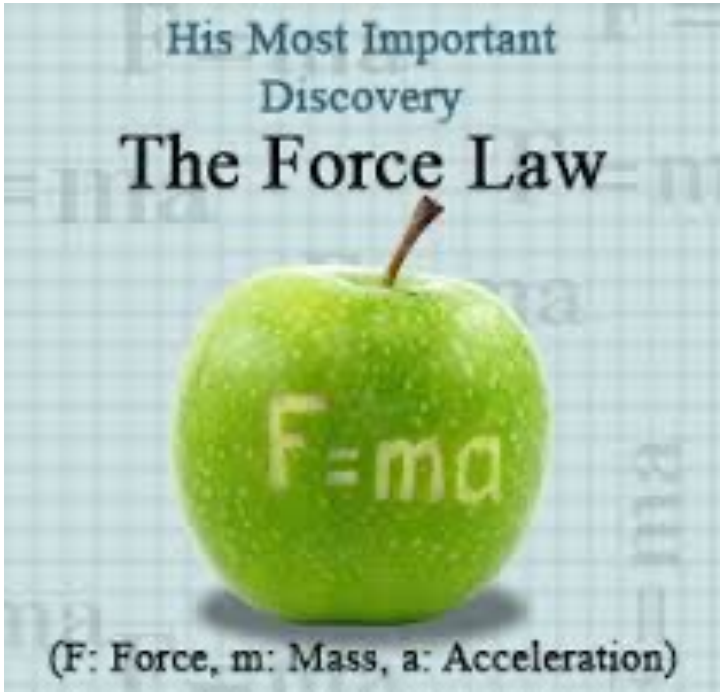
CHAPTER TWO
Newton's Laws of motion



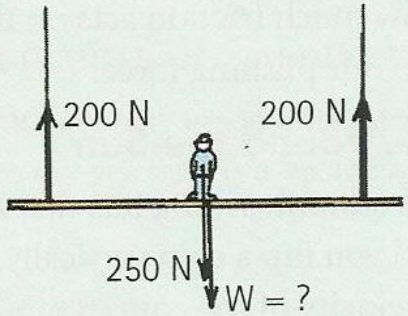
Newton's First Law of Motion

- **Every object continues in a state of rest or uniform speed in a straight line unless acted upon by a nonzero force.**
- In other words:

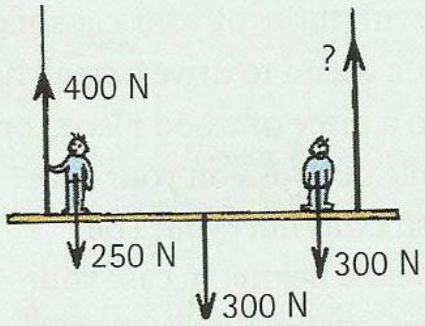
  An object at rest remains at rest if no net force is acting on it, and an object moving continues to move with the same velocity (fixed speed and direction (straight line)) if no net force is acting on it.

Exercises

The sketch shows a painting scaffold in mechanical equilibrium. The person in the middle weighs 250 N, and the tensions in each rope are 200 N. What is the weight of the scaffold?



. A different scaffold that weighs 300 N supports two painters, one of whom weighs 250 N and the other 300 N. The reading on the left scale is 400 N. What is the reading on the right-hand scale?



Exercises

9. Why do you lurch forward in a bus that suddenly slows? Why do you lurch backward when it picks up speed? What law applies here?

9. If you push your desk along the floor with a force of 80 N and it slides at constant speed, then the force of friction acting on the desk is

(a) also 80 N in the direction of your push.

(b) 80 N in the direction opposite to your push.

(c) zero.

(d) None of these.

Newton's First Law of Motion
CHECK YOUR NEIGHBOR

If you swing a stone overhead in a horizontal circle and the string breaks, the tendency of the stone is to follow a

A. curved path.
B. straight-line path.
C. spiral path.
D. vertical path.

Answer is B

Newton's Second Law of Motion
Force and Acceleration

- Applying a nonzero net force on an object causes it to accelerate:

Accelerating object → non-zero NET force

Acceleration is always in the same direction of the net force

- A net force acting in the direction of motion → velocity will increase (acceleration)
- A net force acting in the opposite direction of motion → velocity will decrease (deceleration)
- A net force acting in the perpendicular direction (right angles) → direction will change
- **Acceleration is directly proportional** to the **net force** applied on the object: **Acceleration** ∝ **net force**

Force of hand accelerates the brick

Twice as much force produces twice as much acceleration

Twice the force on twice the mass gives the same acceleration

Newton's Second Law of Motion
Mass and Acceleration

- Recall:
  - Mass: measure of matter in an object. Also it is a measure of inertia (resisting the change in its state of motion)
  - Weight is the FORCE due to gravity on an object.
  - Mass and weight are different, but they are directionally proportional to each other.

- **More mass means less acceleration**, because more mass means more resistance to change in motion.
- The **acceleration** produced by a given net force on an object is **inversely proportional** to the **mass** of the object → **Acceleration ∝ (1 / mass)**

Newton's Second Law of Motion

- Newton's Second Law: *The acceleration produced by a net force on an object is directly proportional to the net force (in the same direction as the net force) and is inversely proportional to the mass of the object.*

$$\text{Acceleration} = \frac{\text{net force}}{\text{mass}} \quad \Rightarrow \quad \boxed{a = \frac{\sum F}{m}}$$

- Note: Units of force = units of mass × units of acceleration → kg.m/s^2 = Newton (N)

Exercise 3: A 100 kg object is pulled by a cable with 2000 N of force. Assuming no friction, what is the resulting acceleration of the car?

Conceptual Exercises

- An object is at rest. Is the net force acting on it zero or greater than zero?
- An object is moving at a constant velocity. Is the net force acting on it zero or greater than zero?
- An object is moving at a constant non-zero acceleration. Is the net force acting on it zero or greater than zero?
- The man pulls the cart shown with a force **P** but still he can't move it
  - Is the net force zero or grater than zero?
  - Is the friction force acting less than **P**, equal to **P**, or greater than **P**?

Conceptual Exercises

- Another man helps him, the cart starts to slide and then it moves at a constant velocity
  - Is the friction force less than the total pulling force **P**, equal to **P**, or greater than **P**?
  - Is the acceleration is zero, or grater than zero (which direction)?
  - Is the net force is zero, or grater than zero?
- A third man helps so that the total pulling force **P** is grater than friction. Answer questions above. What is the direction of acceleration?

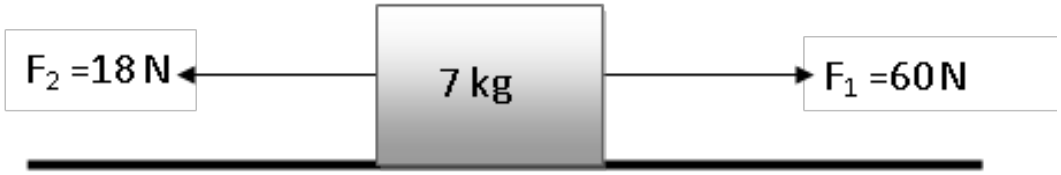
Exercises

Exercise 4: A 2000 kg train accelerates at 2 m/s^2 from rest. What is the net force acting on the train?

Exercise 5: A 2000 kg train accelerates from rest to reach a speed of 6 m/s in 3 seconds. What is the total force acting on the train?

Exercise 6: What is the block's acceleration (magnitude and direction) for each of the following figures?

a) (answer 6 m/s^2)

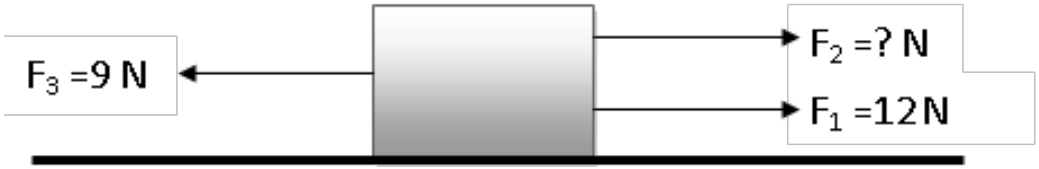


Exercises

b) (answer $-12\ m/s^2$)

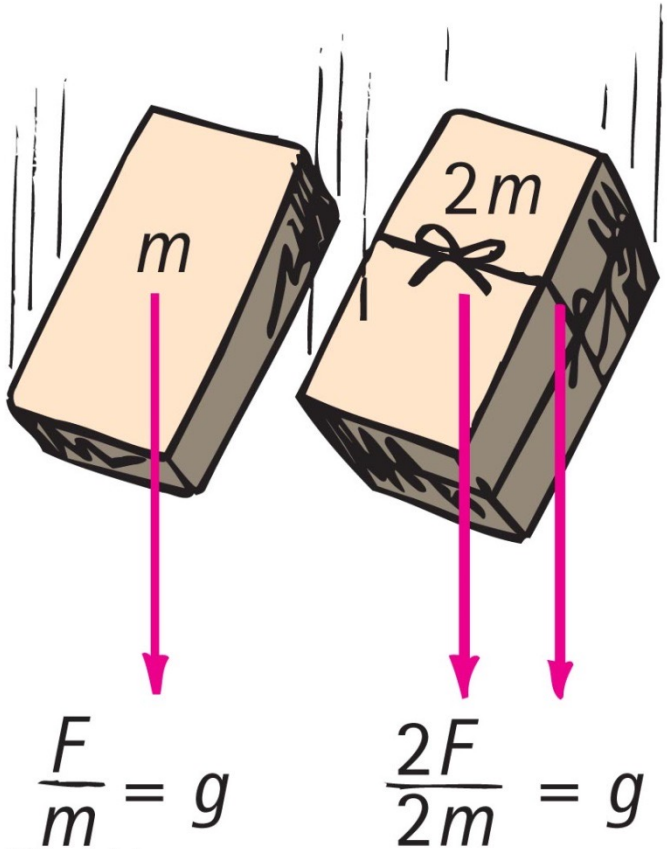
c) (answer $-9\ m/s^2$)

Exercise 7: A 3 kg block is accelerating to the right at 6 m/s^2 under the effect of 3 forces as shown in the figure. What is the value of the unknown force F_2? (answer 15 N)



Newton's Second Law of Motion

- When acceleration is *g* (free fall)
  - When the only force acting on a falling object is gravity, with negligible air resistance, the object is in **free fall**.
  - An object in free fall accelerates toward Earth at 10 m/s per second.
  - Twice the force on twice the mass same acceleration as half the force on half the mass.
  - The ratio of weight to mass is the same for all falling objects in the same locality; hence, their accelerations are the same in the absence of air resistance.



Newton's Second Law of Motion
A situation to ponder…

- When an air-filled glass tube containing a coin and a feather is inverted, the coin falls quickly to the bottom of the tube while the feather flutters to the bottom.

A situation to ponder…
CHECK YOUR NEIGHBOR

When the air is removed by a vacuum pump and the activity is repeated,

A. the feather hits the bottom first, before the coin hits.

B. the coin hits the bottom first, before the feather hits.

C. both the coin and feather drop together side by side.

D. Not enough information.

A situation to ponder…
CHECK YOUR ANSWER

When the air is removed by a vacuum pump and the activity is repeated,

A. the feather hits the bottom first, before the coin hits.

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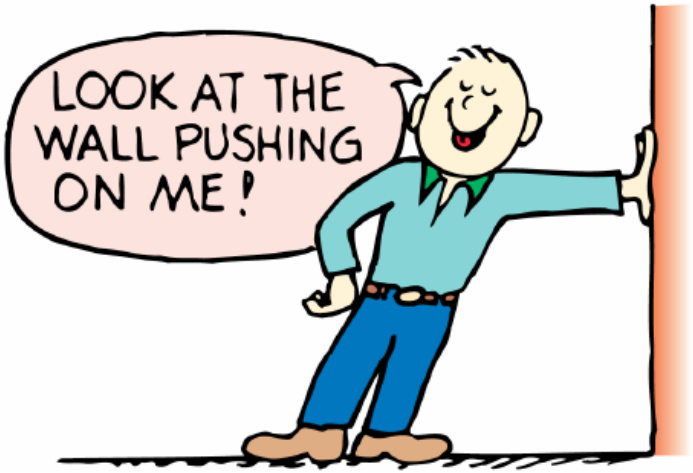
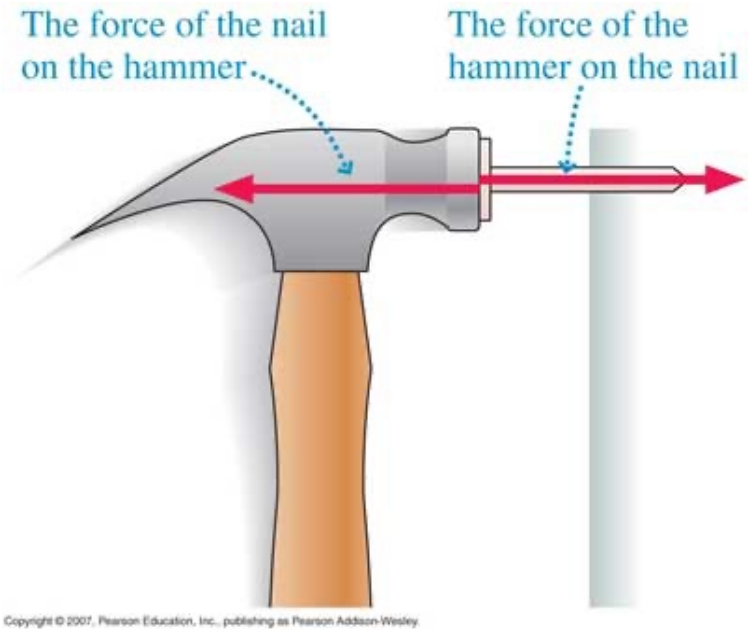
Newton's Third Law of Motion

- A force is not just a single push or pull. A force is a part of a **mutual interaction** between one object and another.

→ **Forces always occur in pairs.**

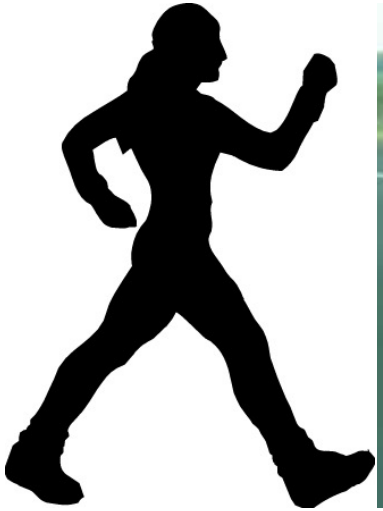


- Examples:
  - Pushing on a wall. Does the wall push you back?!
  - A hummer hitting a nail

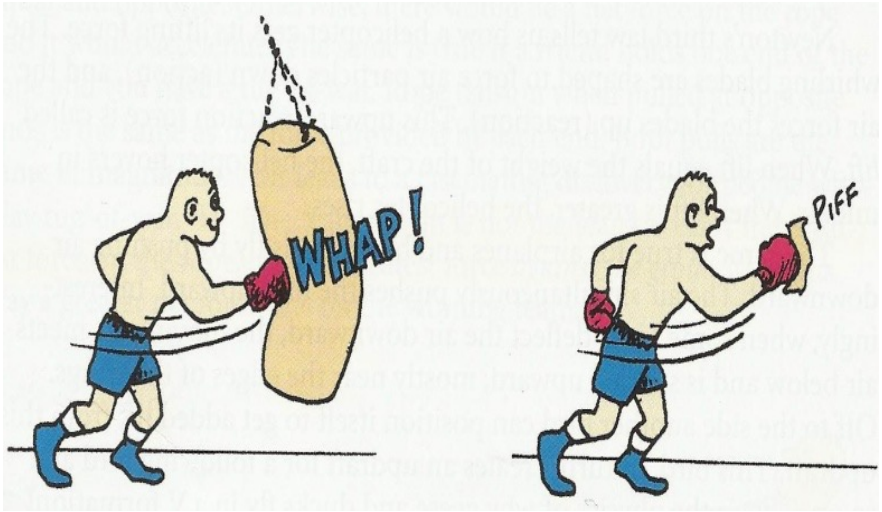


Newton's Third Law of Motion

- Walking on the floor. How do you move?
- A car on the road. What pushes the car? What if ice covers the road?
- Swimming



- When the boxer hits a massive punching bag, the fist hits the bag and the bag hits back on the fist. The fist cannot exert any force unless what is being hit exerts the same amount of reaction force



- When you pull on a cart and it accelerates, the cart pulls back on you by tightening the rope around your hand.

Newton's Third Law: Action and Reaction

- Whenever an object exerts a force on a second object, the second object exerts an equal and opposite force on the first.
- In other words, ***"to every action there is an equal opposing reaction"***

Action Equals Reaction

- For every interaction between things there is always a pair of oppositely directed forces that are equal in strength.

For example:

- If you push hard on something, it pushes hard on you.
- If you touch something gently, it touches you gently in return.
- The way you touch others is the way others touch you.

Action and Reaction Act on Different Objects

- Since action and reaction forces are equal and opposite, why don't they cancel to zero?
  - They don't cancel because action force and its reaction force always act on different objects. Forces cancel only when they act on the same object.

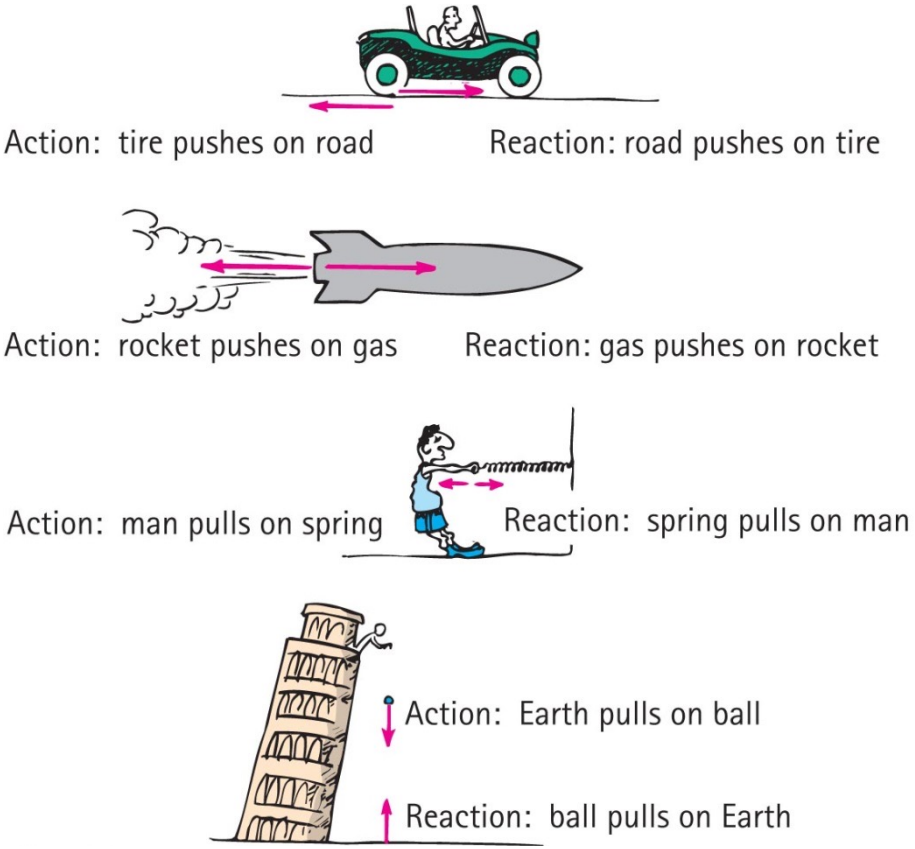
- Two external forces acting on the same object even if they are equal and opposite cannot be action-reaction pair.

Newton's Third Law of Motion

- Action and reaction forces
  - one force is called the action force; the other force is called the reaction force
  - are copairs of a single interaction
  - neither force exists without the other
  - are equal in strength and opposite in direction
  - always act on *different* objects

Newton's Third Law of Motion

- Simple rule to identify action and reaction:
  - Action—object A exerts a force on object B.
  - Reaction—object B exerts a force on object A.



Newton's Third Law of Motion
CHECK YOUR NEIGHBOR

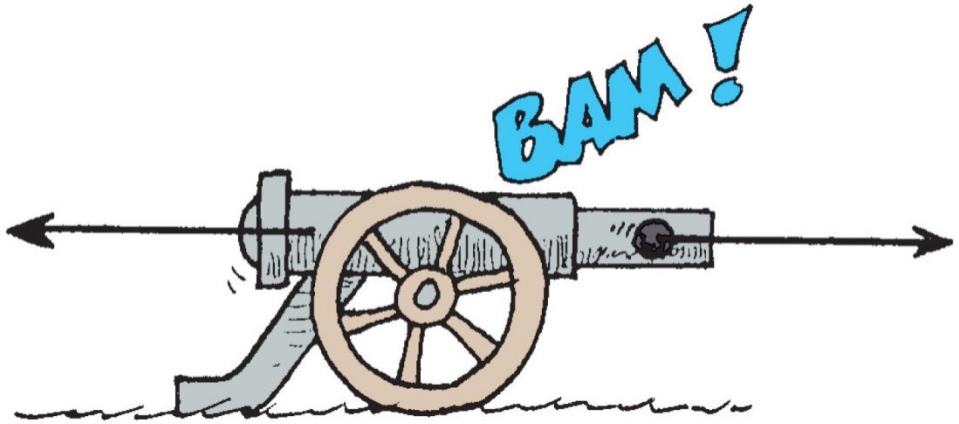
When a cannon is fired, the accelerations of the cannon and cannonball are different, because the

A. forces don't occur at the same time.

B. forces, although theoretically are the same, in practice aren't the same.

C. masses are different.

D. ratios of force to mass are the same.



Newton's Third Law of Motion
CHECK YOUR ANSWER

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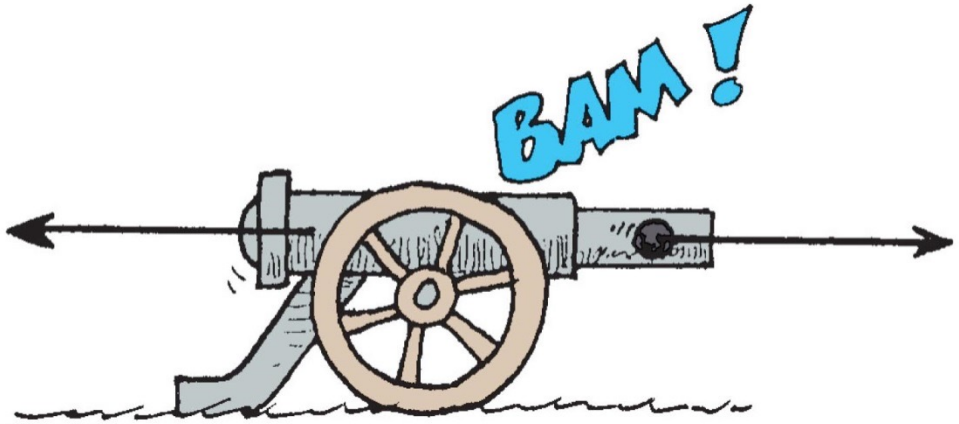
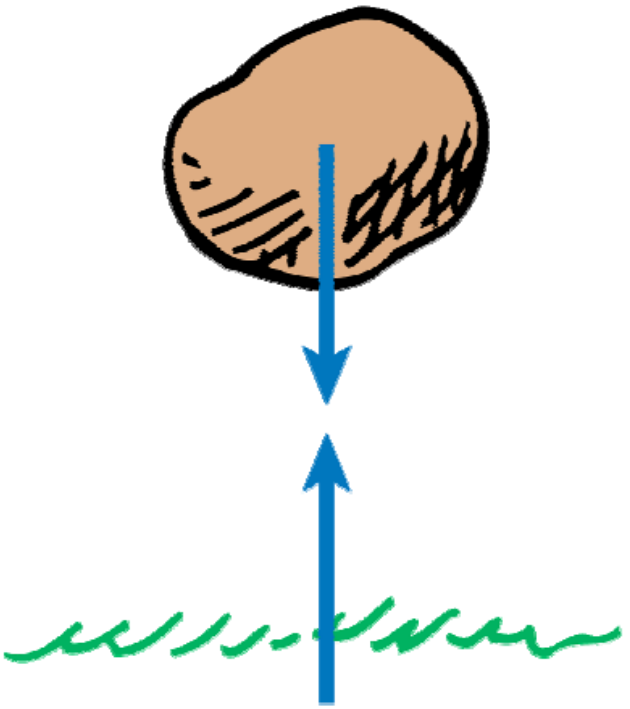


Action and Reaction on Objects of Different Masses

- Earth is pulled up by the boulder with just as much force as the boulder is pulled down by Earth.
  - The forces are equal in strength and opposite in direction.
  - The boulder falls to Earth and Earth falls to the boulder, but the distance Earth falls is much less.
  - Although the pair of forces between the boulder and Earth is the same, the masses are quite unequal.



- **Acceleration** is not only **proportional to the net force**, but it is also **inversely proportional to the mass**. Because Earth has a huge mass, we don't sense its infinitesimally small acceleration.

Action and Reaction on Objects of Different Masses

- When a bullet is fired:
  - the force that the gun exerts on the bullet is exactly **equal** and opposite to the force the bullet exerts on the gun. This is why the gun recoils.
  - But the effect of these two forces is very different because the forces act on **different masses**.

$$\text{Bullet:} \quad \frac{F}{m} = a$$

$$\text{Gun} \quad : \quad \frac{F}{m} = a$$

greater mass object → small acceleration

smaller mass object → large acceleration

Action and Reaction on Objects of Different Masses

- A given force exerted on a small mass produces a large acceleration while the same force exerted on a large mass produces a small acceleration.

- For example, a falling object pulls upward on earth with as much force as earth pulls downward on it. The resulting acceleration of a falling object is evident while the upward acceleration of earth is too small to be detected.

Action and Reaction

- **Think:** A tug of war occurs between boys and girls on a polished floor that's somewhat slippery. If the boys are wearing socks and the girls are wearing rubber-soled shoes, who will surely win, and why?

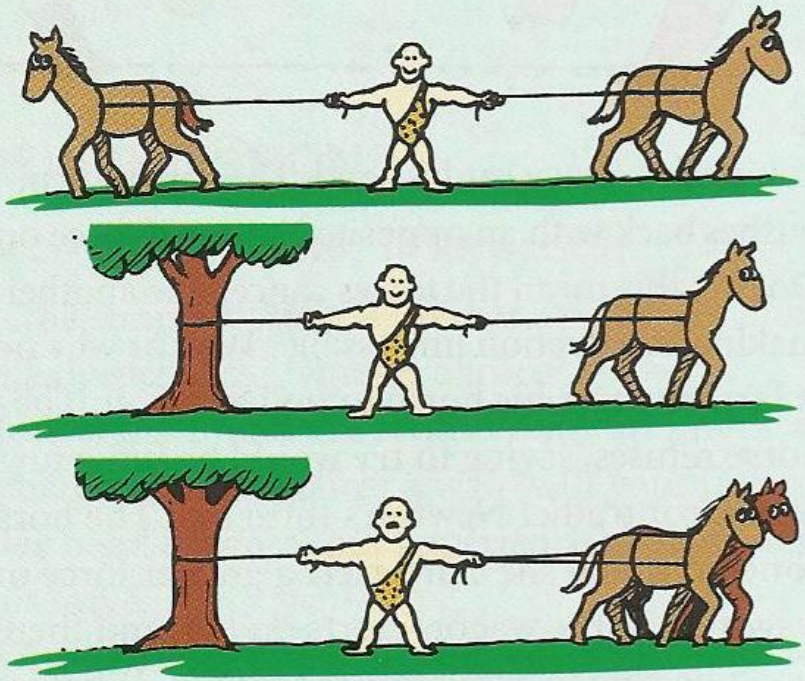
  - *Answer:* The girls will win. The force of friction is greater between the girls' feet and the floor than between the boys' feet and the floor. When both the girls and the boys exert action forces on the floor, the floor exerts a greater reaction force on the girls' feet.

Exercises

12. If a massive truck and small sports car have a head-on collision, upon which vehicle is the collision force greater? Which vehicle experiences the greater acceleration? Explain your answers.

Exercises

14. The strong man can withstand the tension force exerted by the two horses pulling in opposite directions. How would the tension compare if only one horse pulled and the left rope were tied to a tree? How would the tension compare if the two horses pulled in the same direction, with the left rope tied to the tree?



Exercises

1. whenever an object exerts a force on another object, the second object exerts a force of the same size, but in the opposite direction to that of the first object.

a) Always true
b) Sometimes true
c) Always false

2. A student hits a nail with a hammer. During the collision, there is a force

a) on the hammer but not on the nail.
b) on the nail but not on the hammer.
c) on the nail and also on the hammer.

3. A woman weighing 500 N sits on the floor. She exerts a force on the floor of

a) 1000 N. b) 500 N. c) 250 N. d) 50 N. e) 5 N. f) 0 N

Exercises

4. As a 500 N woman sits on the floor, the floor exerts a force on her of

a) 1000 N. b) 500 N. c) 250 N. d) 50 N. e) 0 N.

5. Forces always occur

a) by themselves. b) as single quantities. c) in pairs. d) in triplets. e) in groups

6. Two people, one having twice the mass of the other, play tug-of-war with a 12 meter rope on frictionless ice. After a brief time, they meet. The heavier person slides a distance of

a) 3 m. b) 4 m. c) 5 m. d) 6 m.

Exercises

7. As a ball falls, the action force is the pull of the Earth's mass on the ball. What is the reaction to this force?

a) Air resistance acting against the ball

b) The acceleration of the ball

c) The pull of the ball's mass on the Earth

d) Non-existent in this case

e) none of the above

8. An unfortunate species of mosquito splatters against the windscreen of a moving car. Compared to the force of the car on the mosquito, the force of the mosquito on the car is

a) larger. b) smaller. c) the same. d) Need more information to say

Exercises

9. A Monster-truck and a small car raveling at the same speed have a head-on collision. The vehicle to undergo the greater change in velocity will be the

a) Small car.

b) Monster truck.

c) Both the same

10. According to Newton's third law, if you push gently on something, it will push

a) gently on you.

b) gently on something else.

c) on something only under the right conditions.

d) on you only if you aren't moving.

Exercises

11. The Earth pulls on the Moon, and similarly the Moon pulls on the Earth. This is evidence that

a) Earth and Moon are pulling on each other.

b) Earth's and Moon's pulls comprise an action-reaction pair.

c) both a and b

d) neither a or b

12. A girl holds an apple in her hand. If action is the Earth pulling on the apple, then the reaction is

a) the girl's hand pushing up on the apple.

b) the girl's hand providing a normal force on the apple.

c) both a and b

d) neither a or b