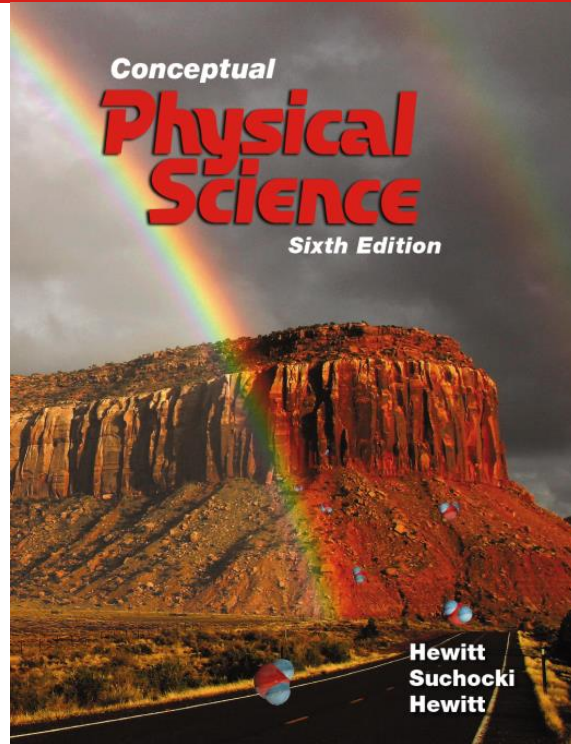


Chapter 2: Newton's Laws of motion



1

Newton's First Law of Motion (The law of inertia)

- **Newton's first law: 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 acts on it, and a moving object continues to move with the same velocity (fixed speed and direction (straight line)) if no net force acts on it.**



2

2

Newton's Laws

→ Third Law

First Law

Law of inertia

$$F_{\text{net}} = 0, \sum \vec{F} = 0$$

Equilibrium / Balanced

$v = 0$
at rest

velocity is constant
(Speed & direction is constant)

$$a = 0$$

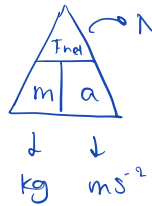
Second Law

• deals w/ acceleration:

- Speeding up
- Slowing down
- Δ dir. of motion

$$F_{\text{net}} = m \times a$$

N kg ms^{-2}



$$F = ma$$

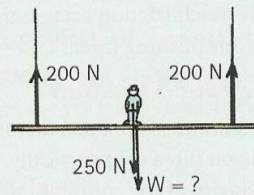
(directly proportional)

$$m = \frac{F_{\text{net}}}{a}, \quad a = \frac{F_{\text{net}}}{m}$$

(inversely proportional)

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?



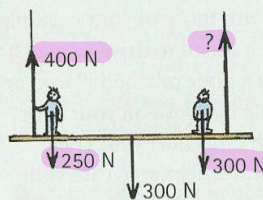
Equilibrium

$$F_{net} = 0$$

$$+200 + 200 - 250 - w = 0$$

$$w = 150 \text{ N downwards}$$

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?



$F_{net} = 0$

$$+400 + ? - 250 - 300 - 300 = 0$$

$$F = 450 \text{ N upwards}$$

3

3

Exercises

→ inertia: the tendency to resist Δ in motion

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?

↳ law of inertia corresponds to Newton's First law

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

- also 80 N in the direction of your push.
- 80 N in the direction opposite to your push.
- zero.
- None of these.

$$F_{net} = 0$$



$F_r = F = 80 \text{ N}$ in the opposite direction

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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

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* any obj revolving around universe is referred to as a satellite

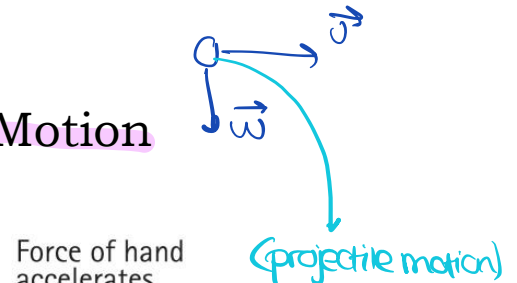
Newton's Second Law of Motion (The law of acceleration)

- 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 \propto net force**



Force of hand accelerates the brick



Twice as much force produces twice as much acceleration $2F \rightarrow 2a$



Twice the force on twice the mass gives the same acceleration



$$F = \frac{m \cdot a}{m}$$

$$F = a$$

$$\frac{2F}{2M} = a$$

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Newton's Second Law of Motion

- 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 directly proportional to each other.

$$a = \frac{f}{m}, \quad m = \frac{f}{a} \rightarrow \text{implies } m \ \& \ a$$

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

7

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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.*

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

- Note: Units of force = units of mass \times units of acceleration \rightarrow kg.m/s² = Newton (N)

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

$$F = ma \quad \rightarrow \quad 2000 \text{ N} = 100 \text{ kg} \cdot a$$

$$\frac{2000 \text{ N}}{100 \text{ kg}} = 20 \text{ m/s}^2$$

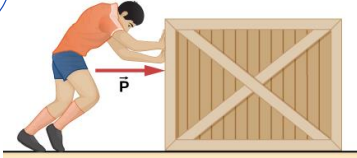
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Conceptual Exercises

- A man pushes a crate, but it **does not move**.

- Is the **net force** zero or greater than zero?
- Is the **acceleration** zero or greater than zero?
- Compared to his pushing force, is the **friction** force less, equal, or greater? → and in the opposite direction



- A man pushes a crate at **constant velocity**. Answer the previous questions. " " speed → direction DOES NOT CHANGE

same answers

- A man pushes a crate such that his pushing force is greater than the friction force.

- Is the **net force** zero or greater than zero?
- Is the **acceleration** zero or greater than zero? What is its direction? → directly proportional in the right direction

9

(a's direction of motion/ force)

Exercises

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

$$F_{\text{net}} = ma$$

$$F_{\text{net}} = 2000 \cdot 2 \rightarrow F_{\text{net}} = 4000 \text{ N}$$

- A 2000 kg train accelerates from rest to reach a speed of 6 m/s in 3 seconds. What is the **net force** acting on the train?

$$F_{\text{net}} = ma$$

$$F_{\text{net}} = 2000 \cdot 2$$

$$F_{\text{net}} = 4000 \text{ N}$$

$$\frac{6 \text{ m/s}}{3 \text{ s}} = 2 \text{ m/s}^2 = a$$

$$\text{OR } a = \frac{v_f - v_i}{t}, a = \frac{6 - 0}{3} = 2 \text{ m/s}^2$$

- A man pushes with a 160 N horizontal force on a 20 kg crate of coffee resting on a warehouse floor. The force of friction on the crate is 80 N . Calculate the acceleration of the crate.



10

$$F_{\text{net}} = 80 \text{ N}$$

$$\text{mass} = 20 \text{ kg}$$

$$F_{\text{net}} = ma$$

$$\frac{80}{20} = \frac{20 \cdot a}{20}$$

$$a = 4 \text{ m/s}^2$$

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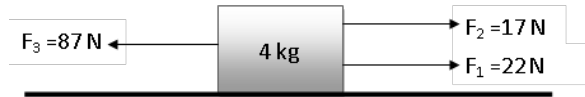
Exercises

- In the figure, what is the magnitude and direction of the block's acceleration? (answer: 12 m/s^2 to the left)

$$F = ma$$

$$\frac{-48 \text{ N}}{4} = \frac{4(a)}{4}$$

$$a = 12 \text{ m/s}^2 \text{ to the left}$$



$$+22 + 17 - 87 = -48 \text{ N}$$

- 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 magnitude of the unknown force F_2 ? (answer: 15 N)

$$F = ma$$

$$F = 3 \cdot 6$$

$$18 \text{ N}$$



$$+? + 12 - 9$$

11

$$18 \text{ N} = +? + 12 - 9$$

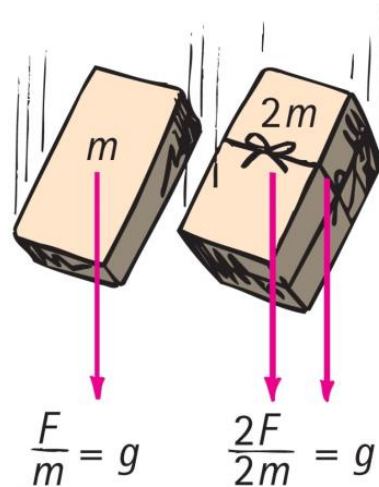
$$18 \text{ N} = +? + 3 \text{ N}$$

$$15 \text{ N} = ?$$

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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.



12

12

two men push a crate to the right with $F_1 = 50\text{N}$ and $F_2 = 75\text{N}$
The crate ($m = 10\text{kg}$) sped up from $15\frac{\text{m}}{\text{s}}$ to $35\frac{\text{m}}{\text{s}}$

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.



13

13

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.



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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.
- 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.

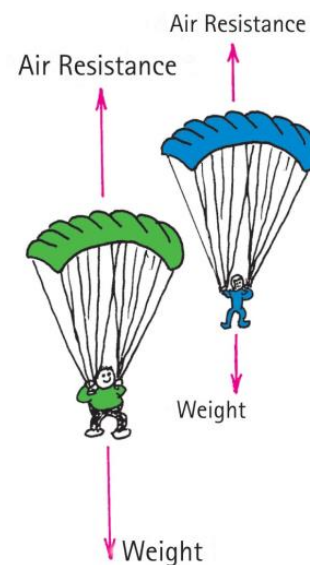


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Newton's Second Law of Motion

- When acceleration is **less than g** (non-free fall)
 - Non-free fall occurs when **two forces act on a falling object**
 - a force due to gravity acting downward
 - air resistance acting upward



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⊗ weight is ALWAYS vertically downward

any qty directed downwards is negative

Newton's Second Law of Motion

CHECK YOUR NEIGHBOR

$m = 2 \text{ kg}$

$-w = 20 \text{ N}$, $-w = mg$, $-w = 2 \times 10$

When a **20-N** falling object encounters **5 N** of air resistance, its acceleration of fall is

(Fair)

- A. less than g .
- B. more than g .
- C. g .
- D. terminated.

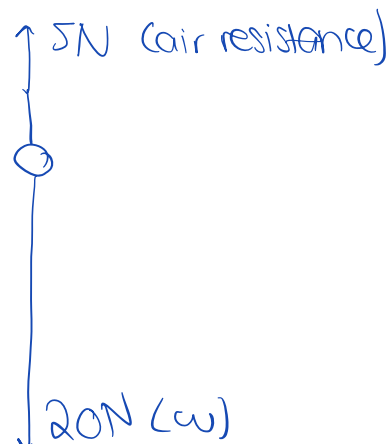
$F_{\text{net}} = ma$

$-w + F_{\text{air}} = ma$

$-20 + 5 = 2a$

$\frac{-15}{2} = \frac{2a}{2}$

$a = -7.5 \text{ m/s}^2$



to determine kg

$w = mg$

$20 = m \cdot 10$, $m = 2 \text{ kg}$

17

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Newton's Second Law of Motion

CHECK YOUR ANSWER

When a 20-N falling object encounters 5 N of air resistance, its acceleration of fall is

- A. less than g .
- B. more than g .
- C. g .
- D. terminated.

Explanation:

Acceleration of non-free fall is always less than g . Acceleration will actually be $(20 \text{ N} - 5 \text{ N}) / 2 \text{ kg} = 7.5 \text{ N/kg} = 7.5 \text{ m/s}^2$.

18

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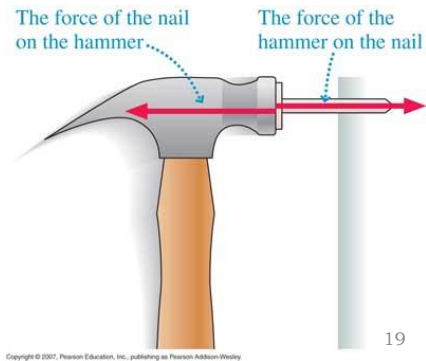
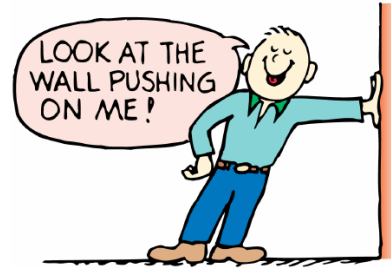
Newton's Third Law of Motion

(The law of action and reaction)

- 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 hammer hitting a nail



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Newton's Third Law of Motion

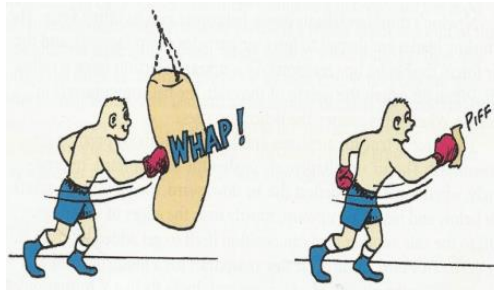
- Walking on the floor. How do you move?
- A car on the road. What pushes the car? What if ice covers the road?
- Swimming



20

20

- 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



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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”***



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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.

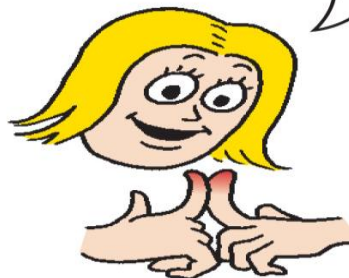


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Action Equals Reaction

When pushing my fingers together I see the same discoloration on each of them. Aha — evidence that each experiences the same amount of force!



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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.

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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

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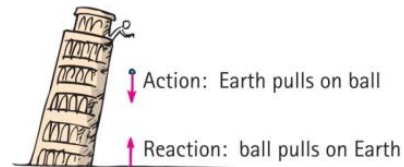
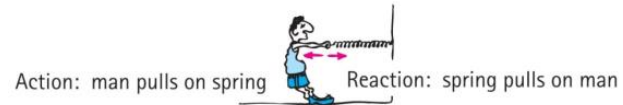
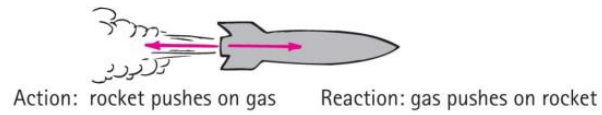
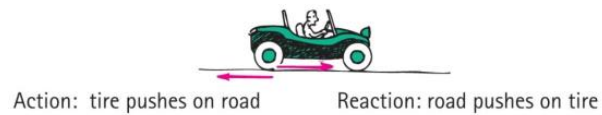
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Newton's Third Law of Motion

- 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.



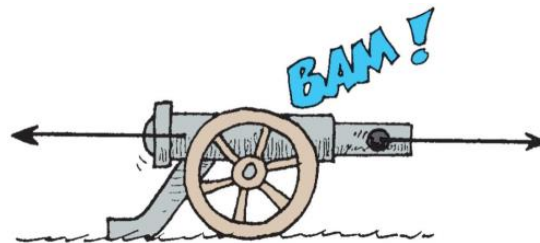
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Newton's Third Law of Motion CHECK YOUR NEIGHBOR

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

- forces don't occur at the same time.
- forces, although theoretically are the same, in practice aren't the same.
- masses are different.
- ratios of force to mass are the same.



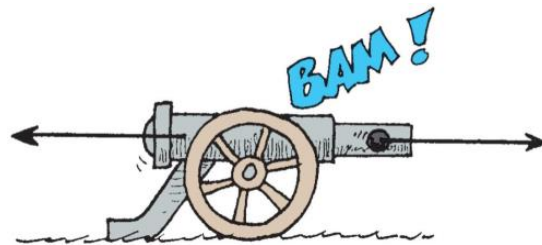
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28

Newton's Third Law of Motion CHECK YOUR ANSWER

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.

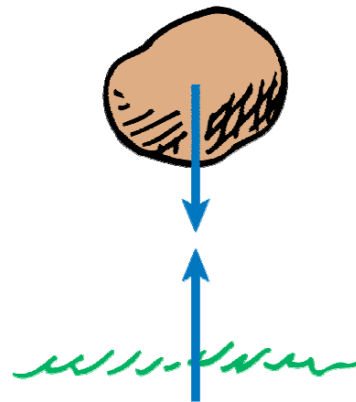


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Action and Reaction on Objects of Different Masses

- 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.



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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**.

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

$$\text{Gun : } \frac{F}{M} = a$$

greater **mass** object → small acceleration

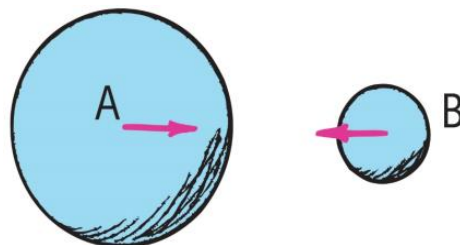
smaller **mass** object → large **acceleration**

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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.
 - 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.
 - Earth and moon pull on each other by the same amount of force



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$$a = \frac{F_{net}}{m}$$



Exercises

(action and reaction)

- If a massive truck collides with a small sports car, upon which vehicle is the collision force greater? Which vehicle experiences greater acceleration? Explain your answer.

$m_{car} < m_{truck}$, $a_{car} > a_{truck}$ $F_{car \text{ on truck}} = F_{truck \text{ on car}}$

- 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

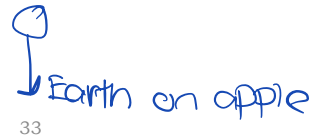
→ based on action + reaction

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

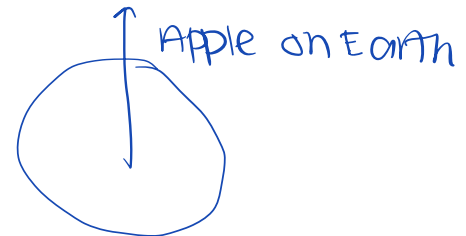
- A girl holds an apple in her hand. If action is the Earth pulling on the apple, then the reaction is

reaction is apple on Earth

- 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



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