Conceptual Physics
11th Edition

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Chapter 4:
NEWTON'S SECOND LAW OF MOTION

This lecture will help you understand:

- Force Causes Acceleration
- Friction
- Mass and Weight
- Mass Resists Acceleration
- Newton's Second Law of Motion
- Free Fall
- Non-Free Fall

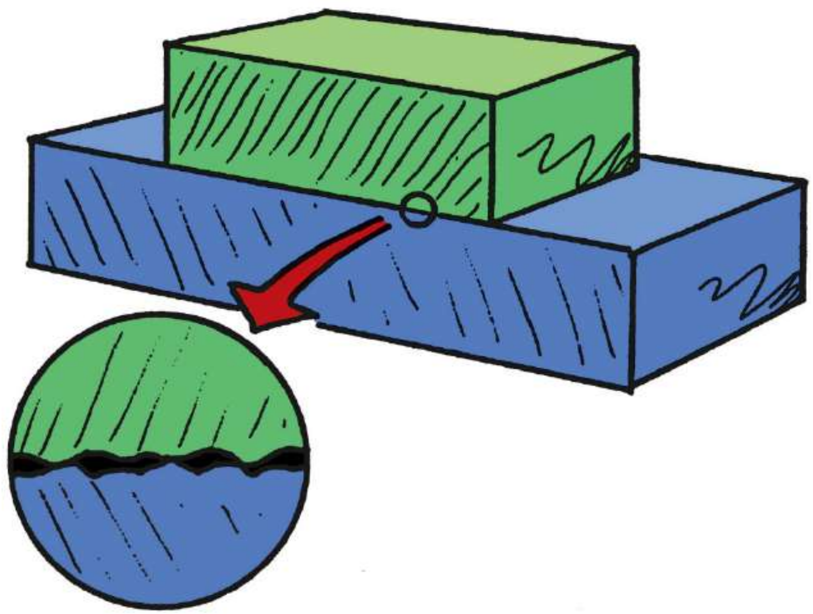
Force causes Acceleration

- Acceleration depends on the *net force*.
- Acceleration is directly proportional to *net force.*
- To increase the acceleration of an object, you must increase the net force acting on it.

Acceleration ~ net force

The Force of Friction

- depends on the kinds of material and how much they are pressed together.
- is due to tiny surface bumps and to “stickiness” of the atoms on a material’s surface.



Example: Friction between a crate on a smooth wooden floor is less than that on a rough floor.

The Force of Friction
CHECK YOUR NEIGHBOR

The force of friction can occur

A. with sliding objects.
B. in water.
C. in air.
D. All of the above.

The Force of Friction
CHECK YOUR ANSWER

The force of friction can occur

A. with sliding objects.
B. in water.
C. in air.
D. All of the above.

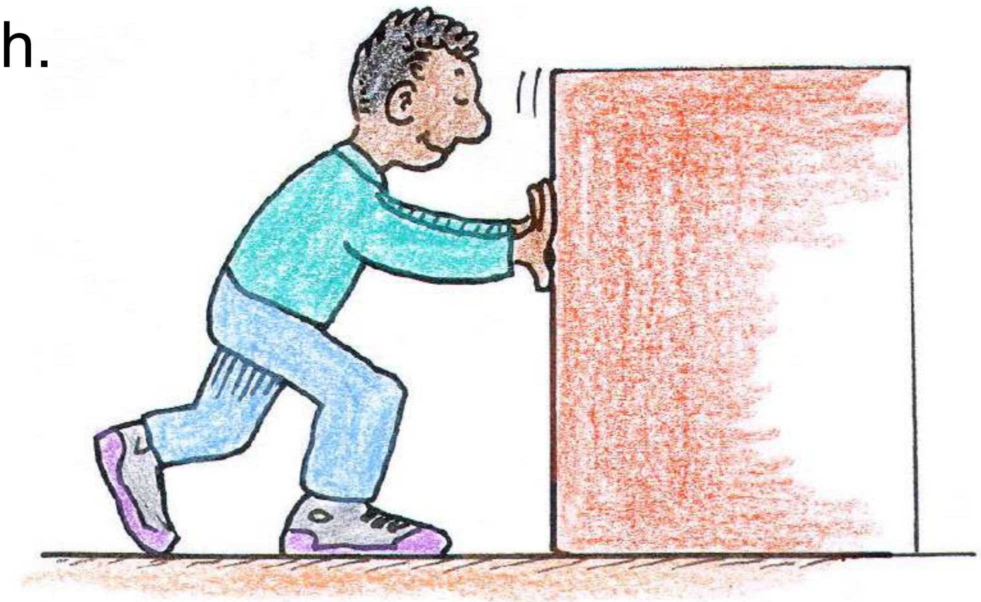
Comment:

Friction can also occur for objects at rest. If you push horizontally on your book and it doesn't move, then friction between the book and the table is equal and opposite to your push.

The Force of Friction
CHECK YOUR NEIGHBOR

When Sanjay pushes a refrigerator across a kitchen floor at a constant speed, the force of friction between the refrigerator and the floor is

A. less than Sanjay's push.
B. equal to Sanjay's push.
C. equal and opposite to Sanjay's push.
D. more than Sanjay's push.



The Force of Friction
CHECK YOUR ANSWER

When Sanjay pushes a refrigerator across a kitchen floor at a constant speed, the force of friction between the refrigerator and the floor is

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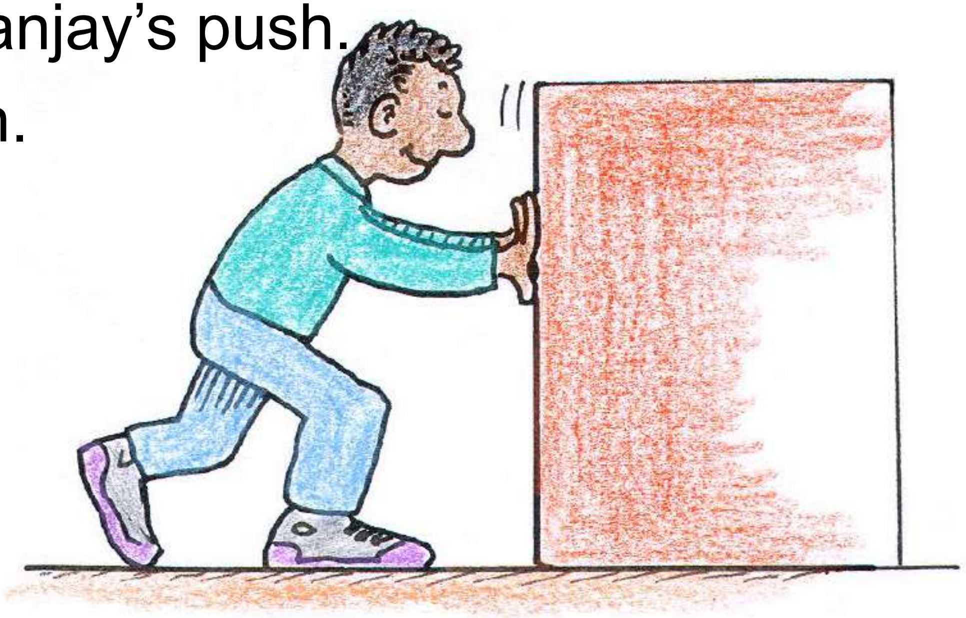
B. equal to Sanjay's push.
C. equal and opposite to Sanjay's push.
D. more than Sanjay's push.

The Force of Friction
CHECK YOUR NEIGHBOR

When Sanjay pushes a refrigerator across a kitchen floor at an *increasing speed*, the amount of friction between the refrigerator and the floor is

A. less than Sanjay's push.
B. equal to Sanjay's push.
C. equal and opposite to Sanjay's push.
D. more than Sanjay's push.



The Force of Friction
CHECK YOUR ANSWER

When Sanjay pushes a refrigerator across a kitchen floor at an *increasing speed*, the amount of friction between the refrigerator and the floor is

A. less than Sanjay's push.
B. equal to Sanjay's push.
C. equal and opposite to Sanjay's push.
D. more than Sanjay's push.

Explanation:

The increasing speed indicates a net force greater than zero. The refrigerator is not in equilibrium.

Mass and Weight

- Mass: *The quantity of matter in an object. It is also the measure of the inertia or sluggishness that an object exhibits in response to any effort made to start it, stop it, or change its state of motion in any way.*

- Weight: *The force upon an object due to gravity.*

Mass and Weight

Mass

- A measure of the inertia of a material object
- Independent of gravity

Greater inertia $\Rightarrow$ greater mass

- Unit of measurement is the kilogram (kg)

Weight

- The force on an object due to gravity
- Scientific unit of force is the newton (N)
- Unit is also the pound (lb)

Mass—A Measure of Inertia
CHECK YOUR NEIGHBOR

If the mass of an object is halved, the weight of the object is

A. halved.
B. twice.
C. depends on location.
D. None of the above.

Mass—A Measure of Inertia
CHECK YOUR ANSWER

If the mass of an object is halved, the weight of the object is

A. halved.
B. twice.
C. depends on location.
D. None of the above.

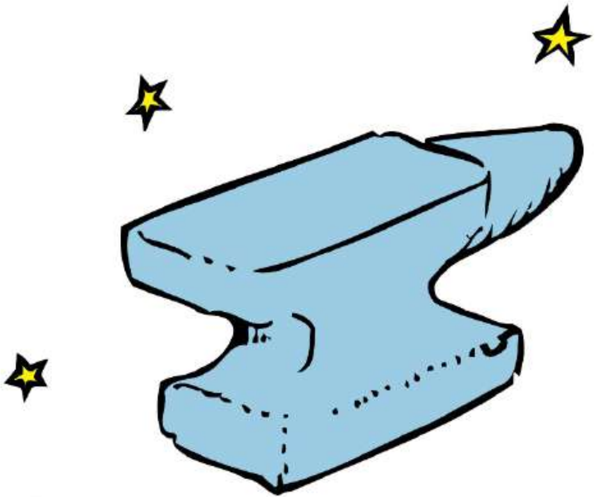
Mass and Weight

Mass and weight in everyday conversation are interchangeable.

Mass, however, is different and more fundamental than weight.

Mass versus weight

- on the Moon and Earth:
  - Weight of an object on the Moon is less than on Earth.
  - Mass of an object is the same in both locations.



Mass and Weight

1 kilogram weighs 10 newtons
(9.8 newtons to be precise).

Relationship between kilograms and pounds:

1 kg = 2.2 lb = 10 N at Earth's surface

- 1 lb = 4.45 N
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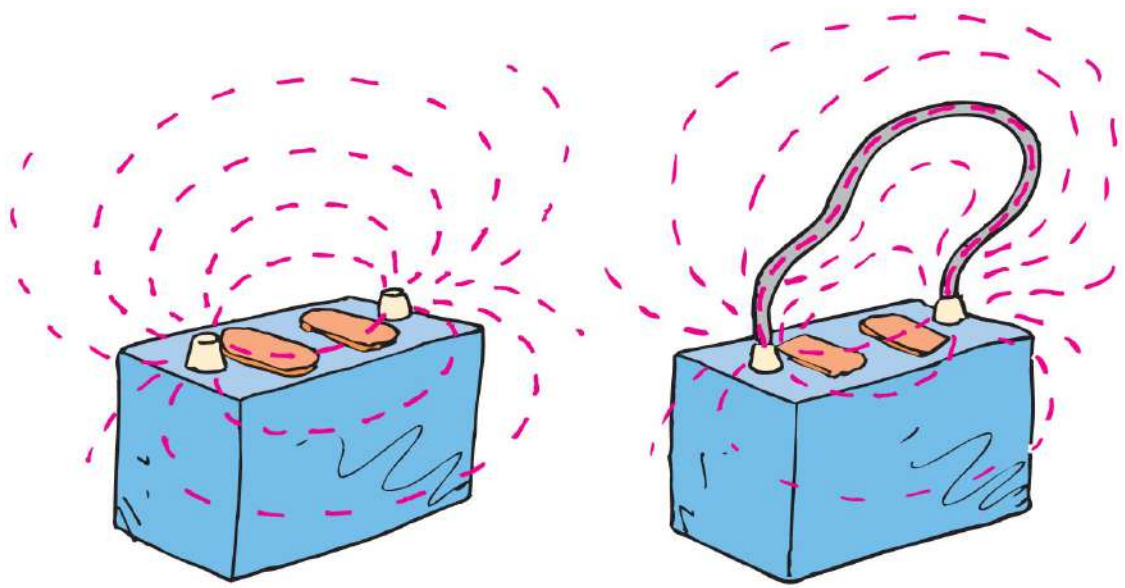
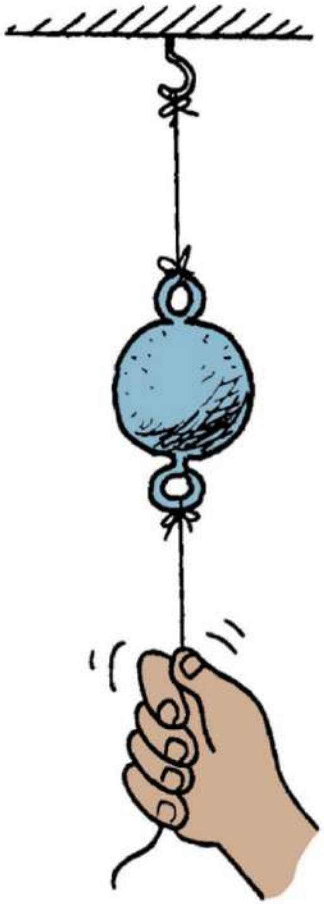


Mass and Weight
CHECK YOUR NEIGHBOR

When the string is pulled down slowly, the top string breaks, which best illustrates the

A. weight of the ball.
B. mass of the ball.
C. volume of the ball.
D. density of the ball.



Mass and Weight
CHECK YOUR ANSWER

When the string is pulled down slowly, the top string breaks, which best illustrates the

A.weight of the ball.

B. mass of the ball.

C. volume of the ball.

D. density of the ball.

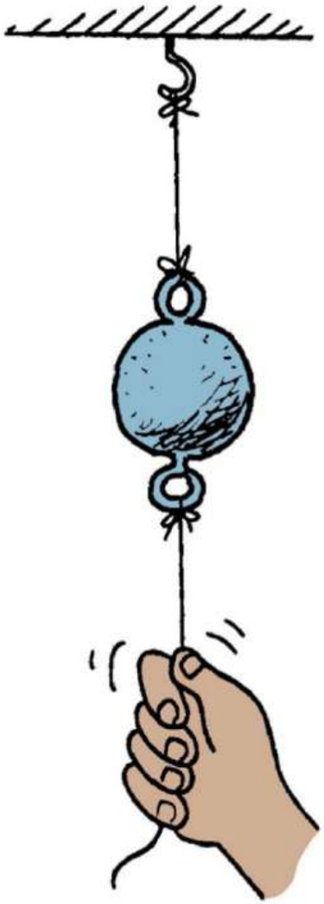
Explanation:

Tension in the top string is the pulling tension plus the weight of the ball, both of which break the top string.

Mass and Weight
CHECK YOUR NEIGHBOR

When the string is pulled down quickly, the bottom string breaks, which best illustrates the

A. weight of the ball.
B. mass of the ball.
C. volume of the ball.
D. density of the ball.



Mass and Weight
CHECK YOUR ANSWER

When the string is pulled down quickly, the bottom string breaks, which best illustrates the

A. weight of the ball.

B. mass of the ball.

C. volume of the ball.

D. density of the ball.

Explanation:

It is the “laziness” of the ball that tends to keep it at rest, resulting in the breaking of the bottom string.

Mass Resists Acceleration

The same force applied to

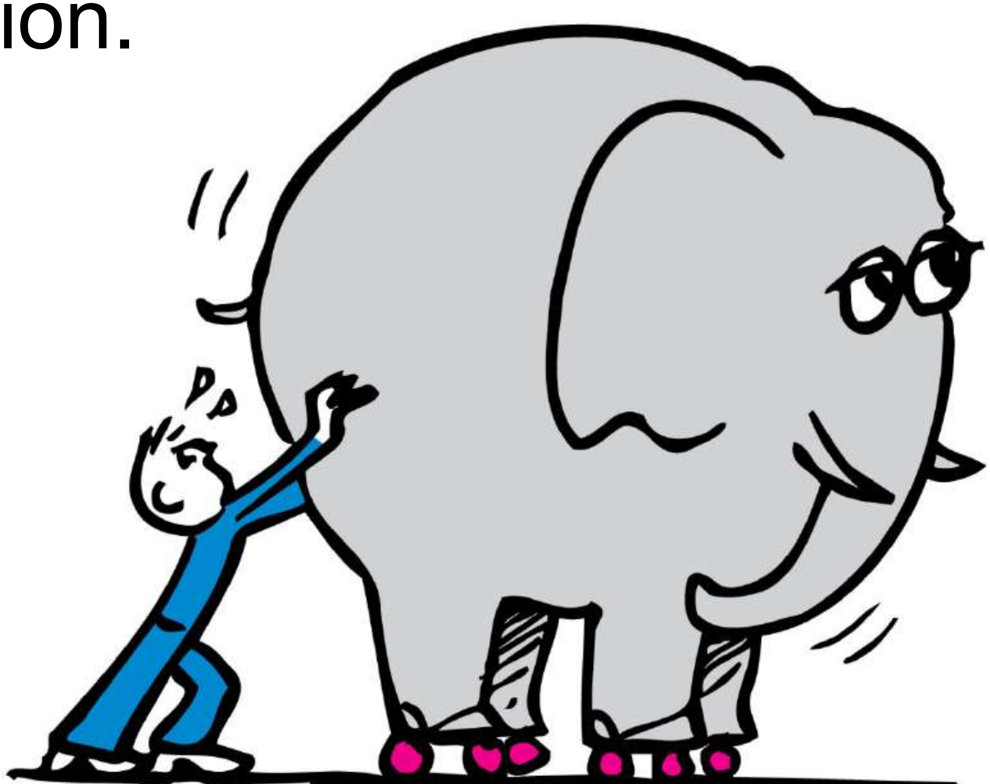
- Twice the mass produces half the acceleration.
- 3 times the mass, produces 1/3 the acceleration.

$$\text{Acceleration} \sim \frac{1}{\text{mass}}$$

Acceleration is inversely proportional to *mass.*

Newton's Second Law of Motion

Isaac Newton was the first to connect the concepts of force and mass to produce acceleration.



Newton’s Second Law of Motion

Newton’s second law (the law of acceleration) relates acceleration to force.

The acceleration produced by a net force on an object is directly proportional to the net force, is in the same direction as the net force, and is inversely proportional to the mass of the object.

Newton's Second Law of Motion

In equation form:

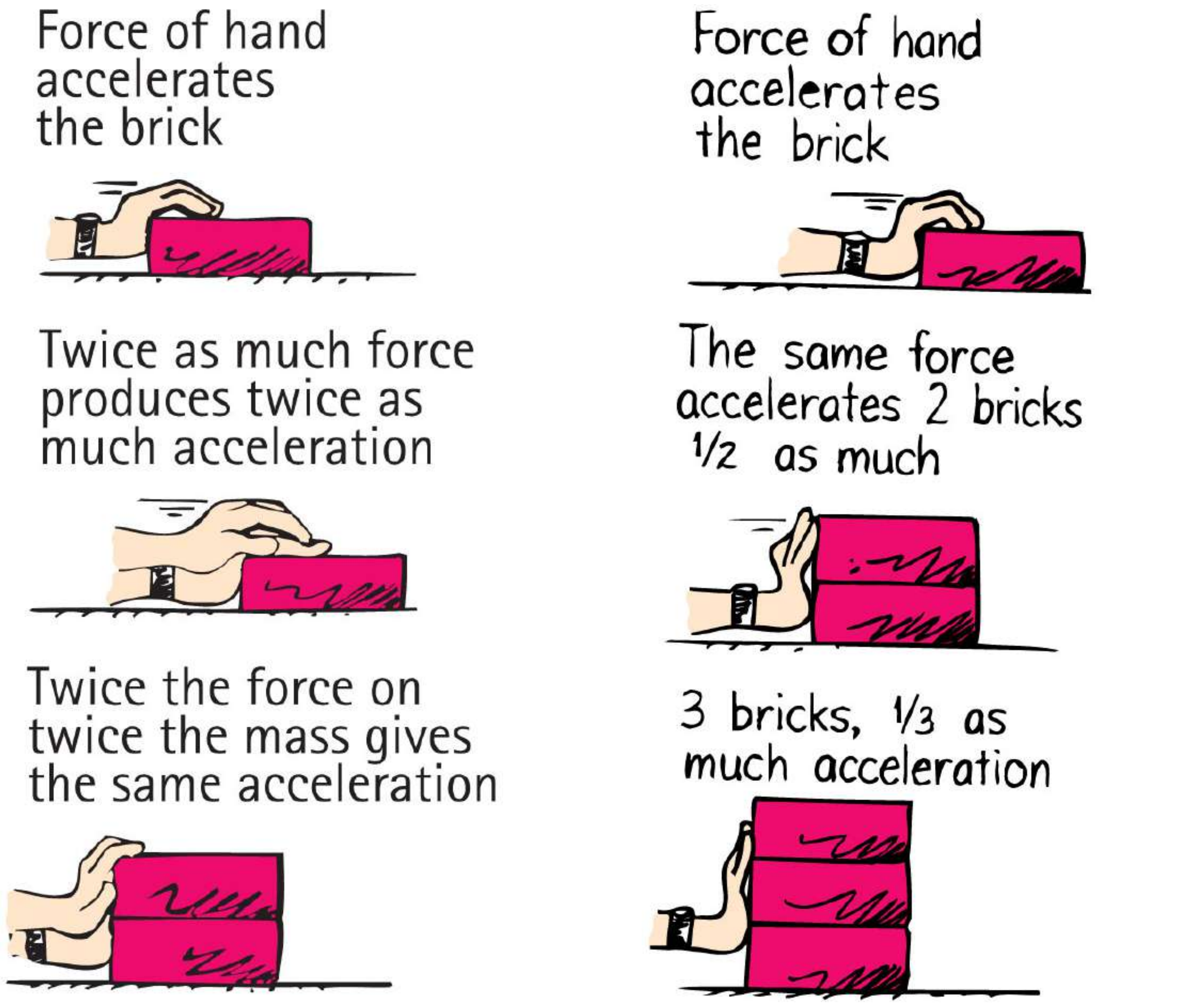
$$\text{Acceleration} = \frac{\text{net force}}{\text{mass}}$$

Example:

If net force acting on object is doubled $\Rightarrow$ object's acceleration will be doubled.

If mass of object is doubled $\Rightarrow$ object's acceleration will be halved.

Newton's Second Law of Motion



Newton's Second Law of Motion
CHECK YOUR NEIGHBOR

Consider a cart pushed along a track with a certain force. If the force remains the same while the mass of the cart decreases to half, the acceleration of the cart

A. remains relatively the same.

B. halves.

C. doubles.

D. changes unpredictably.

Newton's Second Law of Motion
CHECK YOUR ANSWER

Consider a cart pushed along a track with a certain force. If the force remains the same while the mass of the cart decreases to half, the acceleration of the cart

remains relatively the same.
halves.
doubles.
changes unpredictably.

Explanation:
Acceleration = net force / mass
Because, mass is in the denominator, acceleration *increases* as mass *decreases.*

So, if mass is *halved*, acceleration *doubles.*

Newton's Second Law of Motion
CHECK YOUR NEIGHBOR

Push a cart along a track so twice as much net force acts on it. If the acceleration remains the same, what is a reasonable explanation?

A. The mass of the cart doubled when the force doubled.
B. The cart experiences a force that it didn't before.
C. The track is not level.
D. Friction reversed direction.

Newton's Second Law of Motion
CHECK YOUR ANSWER

Push a cart along a track so twice as much net force acts on it. If the acceleration remains the same, what is a reasonable explanation?

A. The mass of the cart doubled when the force doubled.

B. The cart experiences a force that it didn't before.

C. The track is not level.

D. Friction reversed direction.

Explanation:

Acceleration = net force / mass

If force doubles, acceleration will also double,

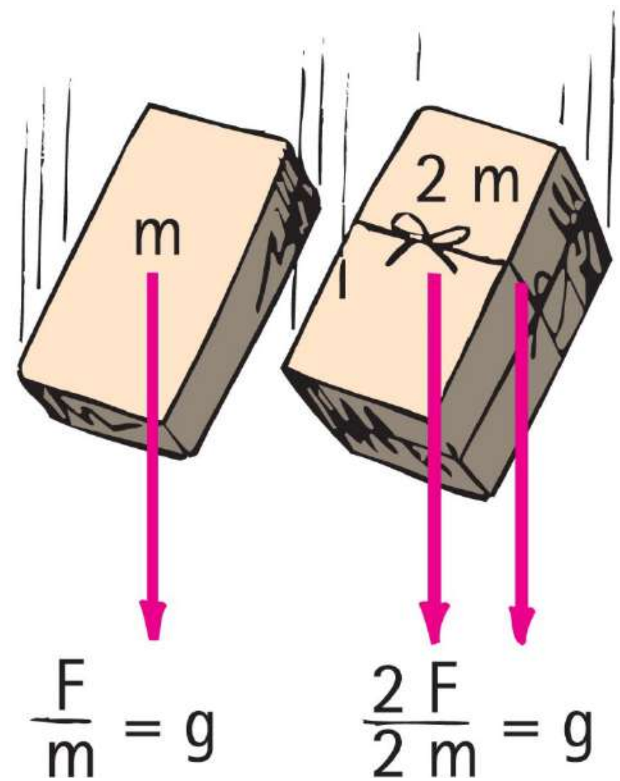
But it does not, so mass must also be doubling to cancel out effects of force doubling.

Free Fall

The *greater* the mass of the object…

- the *greater* its force of attraction toward the Earth.
- the *smaller* its tendency to move i.e., the greater its inertia.

So, the acceleration is the *same*.
It is equal to the acceleration due to gravity: 10 m/s^2
(precisely 9.8 m/s^2).



Free Fall

When acceleration is *g*—free fall

- Newton's second law provides an explanation for the equal accelerations of freely falling objects of various masses.
- Acceleration is equal when air resistance is negligible.
- Acceleration depends on force (weight) and inertia.

Free Fall
CHECK YOUR NEIGHBOR

At one instant, an object in free fall has a speed of 40 m/s. Its speed 1 second later is

A. also 40 m/s.
B. 45 m/s.
C. 50 m/s.
D. None of the above.

Free Fall
CHECK YOUR ANSWER

At one instant, an object in free-fall has a speed of 40 m/s. Its speed 1 second later is

A. also 40 m/s.
B. 45 m/s.
C. 50 m/s.
D. None of the above.

Comment:

We assume the object is falling downward.

Free Fall
CHECK YOUR NEIGHBOR

A 5-kg iron ball and a 10-kg iron ball are dropped from rest. For negligible air resistance, the acceleration of the heavier ball will be

A. less.

B. the same.

C. more.

D. undetermined.

Free Fall
CHECK YOUR ANSWER

A 5-kg iron ball and a 10-kg iron ball are dropped from rest. For negligible air resistance, the acceleration of the heavier ball will be

A. less.

B. the same.

C. more.

D. undetermined.

Free Fall
CHECK YOUR NEIGHBOR

A 5-kg iron ball and a 10-kg iron ball are dropped from rest. When the free-falling 5-kg ball reaches a speed of 10 m/s, the speed of the free-falling 10-kg ball is

A. less than 10 m/s.
B. 10 m/s.
C. more than 10 m/s.
D. undetermined.

Free Fall
CHECK YOUR ANSWER

A 5-kg iron ball and a 10-kg iron ball are dropped from rest. When the free-falling 5-kg ball reaches a speed of 10 m/s, the speed of the free-falling 10-kg ball is

A. less than 10 m/s.

B. 10 m/s.

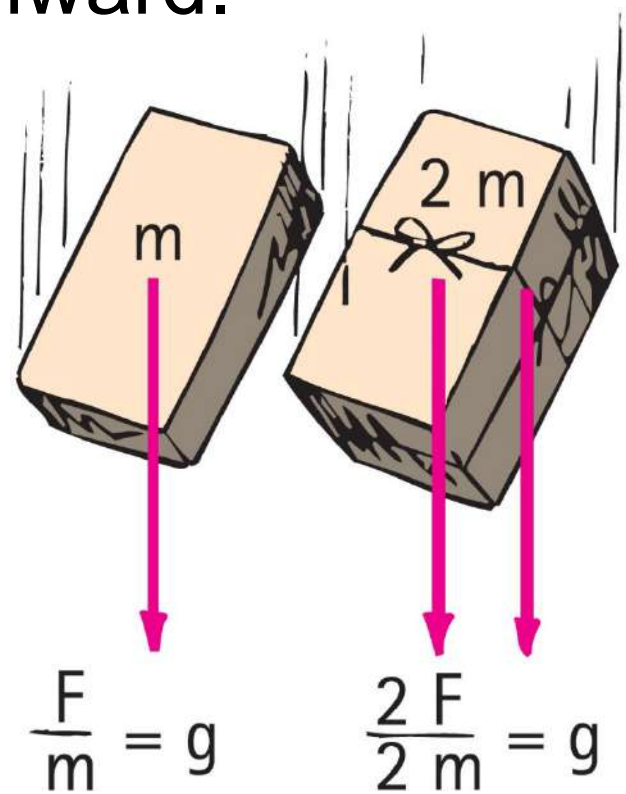
C. more than 10 m/s.

D. undetermined.

Non-Free Fall

When an object falls downward through the air it experiences

- force of gravity pulling it downward.
- air drag force acting upward.



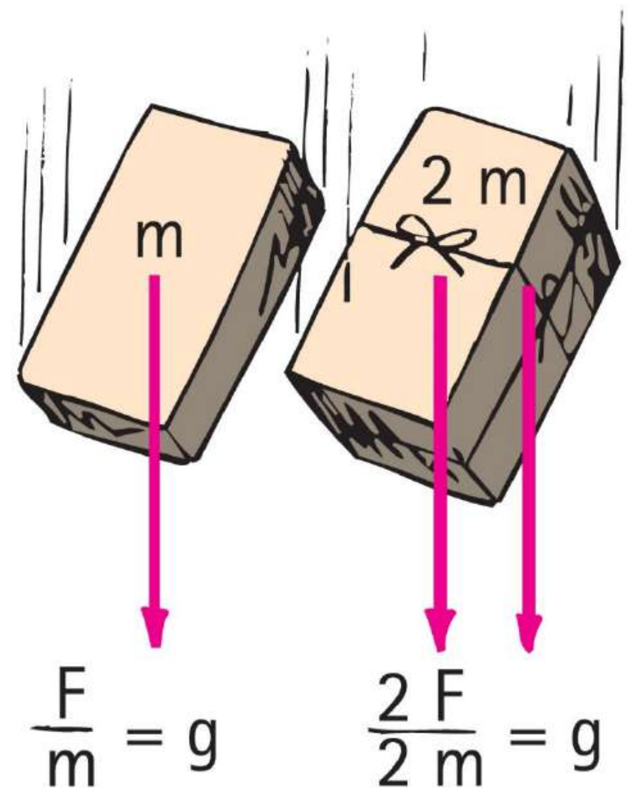
Non-Free Fall

When acceleration of fall is less than *g*, non-free fall

- occurs when air resistance is non-negligible.
- depends on two things:
  - speed and
  - frontal surface area.

Non-Free Fall

- When the object is moving fast enough that force of gravity equals its air resistance
- Then no net force
  - $\Rightarrow$ No acceleration
  - $\Rightarrow$ Velocity does not change



Non-Free Fall

Terminal speed

- occurs when acceleration terminates (when air resistance equals weight and net force is zero).

Terminal velocity

- same as terminal speed, with direction implied or specified.

Non-Free Fall—Example

- A skydiver jumps from plane.
- Weight is the only force until air resistance acts.
- As falling speed increases, air resistance on diver builds up, net force is reduced, and acceleration becomes less.
- When air resistance equals the diver's weight, net force is zero and acceleration terminates.
- Diver reaches terminal velocity, then continues the fall at constant speed.

Non-Free Fall
CHECK YOUR NEIGHBOR

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.

Non-Free Fall
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.

Comment:

Acceleration of a non-free fall is always less than *g*. Acceleration will actually be (20 N – 5 N)/2 kg = 7.5 m/s^2.

Non-Free Fall
CHECK YOUR NEIGHBOR

If a 50-N person is to fall at terminal speed, the air resistance needed is

A. less than 50 N.
B. 50 N.
C. more than 50 N.
D. None of the above.

Non-Free Fall
CHECK YOUR ANSWER

If a 50-N person is to fall at terminal speed, the air resistance needed is

A. less than 50 N.

B. 50 N.

C. more than 50 N.

D. None of the above.

Explanation:

Then, $\Sigma F = 0$ and acceleration = 0.

Non-Free Fall
CHECK YOUR NEIGHBOR

As the skydiver falls faster and faster through the air, air resistance

A. increases.
B. decreases.
C. remains the same.
D. Not enough information.

Non-Free Fall
CHECK YOUR ANSWER

As the skydiver falls faster and faster through the air, air resistance

A. increases.

B. decreases.

C. remains the same.

D. Not enough information.

Non-Free Fall
CHECK YOUR NEIGHBOR

As the skydiver continues to fall faster and faster through the air, net force

A. increases.
B. decreases.
C. remains the same.
D. Not enough information.

Non-Free Fall
CHECK YOUR ANSWER

As the skydiver continues to fall faster and faster through the air, net force

A. increases.

B. decreases.

C. remains the same.

D. Not enough information.

Non-Free Fall
CHECK YOUR NEIGHBOR

As the skydiver continues to fall faster and faster through the air, her acceleration

A. increases.
B. decreases.
C. remains the same.
D. Not enough information.

Non-Free Fall
CHECK YOUR ANSWER

As the skydiver continues to fall faster and faster through the air, her acceleration

A. increases.

B. decreases.

C. remains the same.

D. Not enough information.

Comment
If this question were asked first in the sequence of skydiver questions, many would answer it incorrectly. Would this have been you?

Non-Free Fall
CHECK YOUR NEIGHBOR

Consider a heavy and light person jumping together with same-size parachutes from the same altitude. Who will reach the ground first?

A. The light person.
B. The heavy person.
C. Both will reach at the same time.
D. Not enough information.

Non-Free Fall
CHECK YOUR ANSWER

Consider a heavy and light person jumping together with same-size parachutes from the same altitude. Who will reach the ground first?

A. The light person
B. The heavy person
C. Both will reach at the same time.
D. Not enough information.

Explanation:
They both have the same drag force (for the same speed).
The man (heavier) has a greater downward force than the woman (lighter).
The man has to drop farther to receive drag force equal to his downward force, so a higher terminal velocity.

Free Fall vs. Non-Free Fall

Coin and feather fall with air present

- Feather reaches terminal velocity very quickly and falls slowly at constant speed, reaching the bottom after the coin does.
- Coin falls very quickly and air resistance doesn't build up to its weight over short-falling distances, which is why the coin hits the bottom much sooner than the falling feather.
-

Non-Free Fall
CHECK YOUR NEIGHBOR

When the air is removed by a vacuum pump and the coin and feather 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.

Non-Free Fall
CHECK YOUR ANSWER

When the air is removed by a vacuum pump and the coin and feather 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.

Free Fall vs. Non-Free Fall

Coin and feather fall in vacuum

- There is no air, because it is vacuum.
- So, no air resistance.
- Coin and feather fall together.