Chapter 4:

NEWTON’S SECOND LAW OF MOTION

Objectives

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

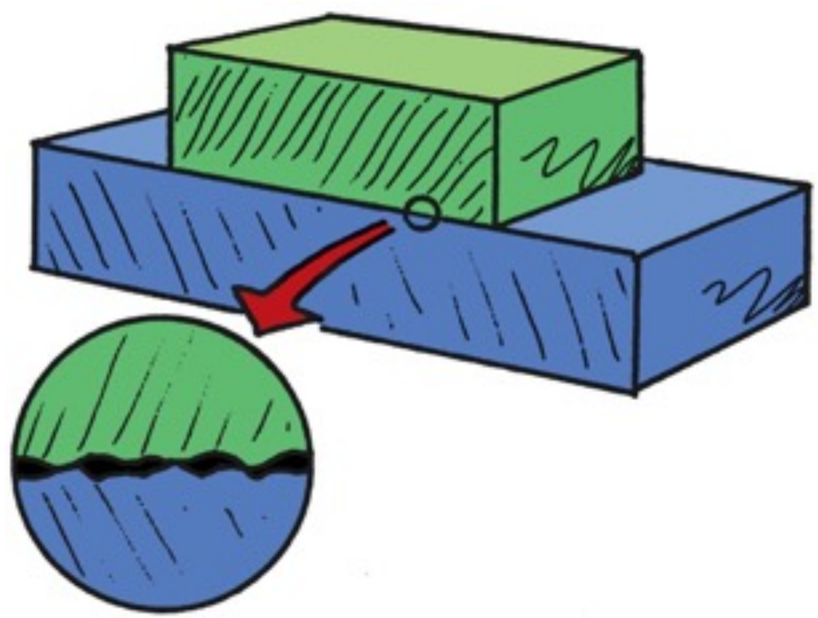
Force causes Acceleration

- 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 can occur

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

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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.

When Sanjay pushes a refrigerator across a kitchen floor at <u>a constant speed</u>, 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.

When Sanjay pushes a refrigerator across a kitchen floor at <u>a constant speed</u>, 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.

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.

When Sanjay pushes a refrigerator across a kitchen floor at an *<u>increasing speed</u>*, 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)

1N = 0.22 lb

Mass and Weight

- In other words, mass is a measurement of how much matter is in an object.
- Weight is a measurement of how hard gravity is pulling on that object

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

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.

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C. depends on location.

D. None of the above.

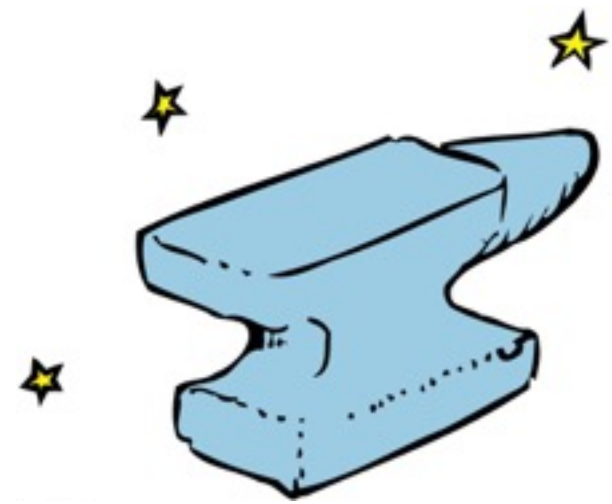
Mass and Weight

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 Resists Acceleration

The same force applied to

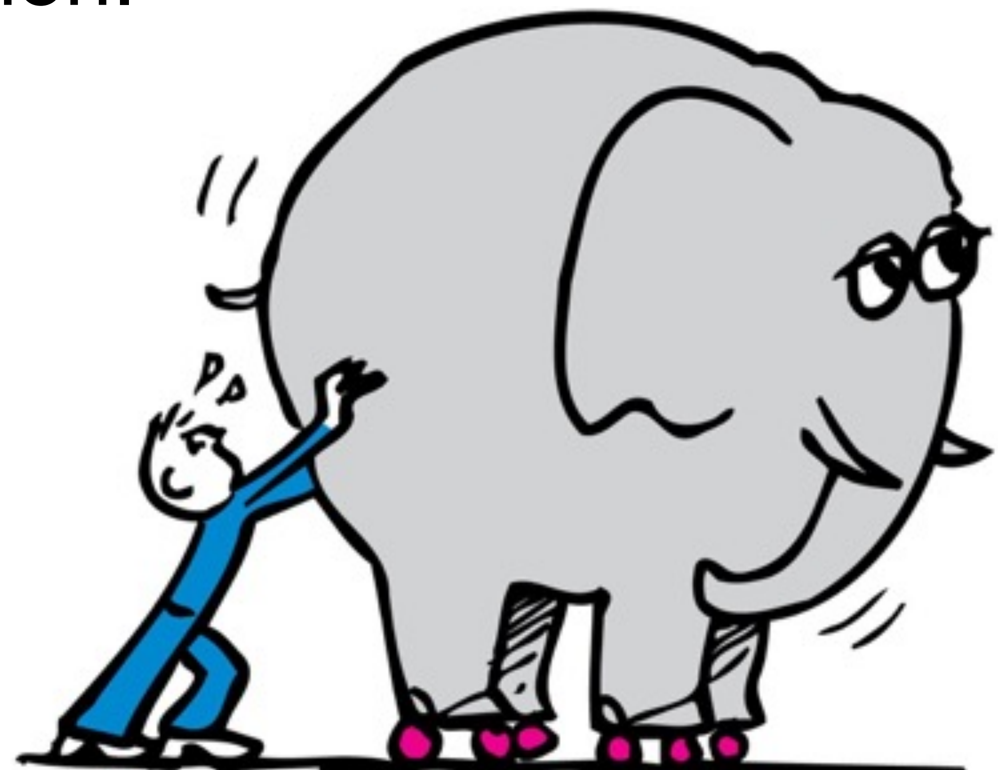
- Twice the mass produces half the acceleration.
- 3 times the mass, produces 1/3 the acceleration.

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

- 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:

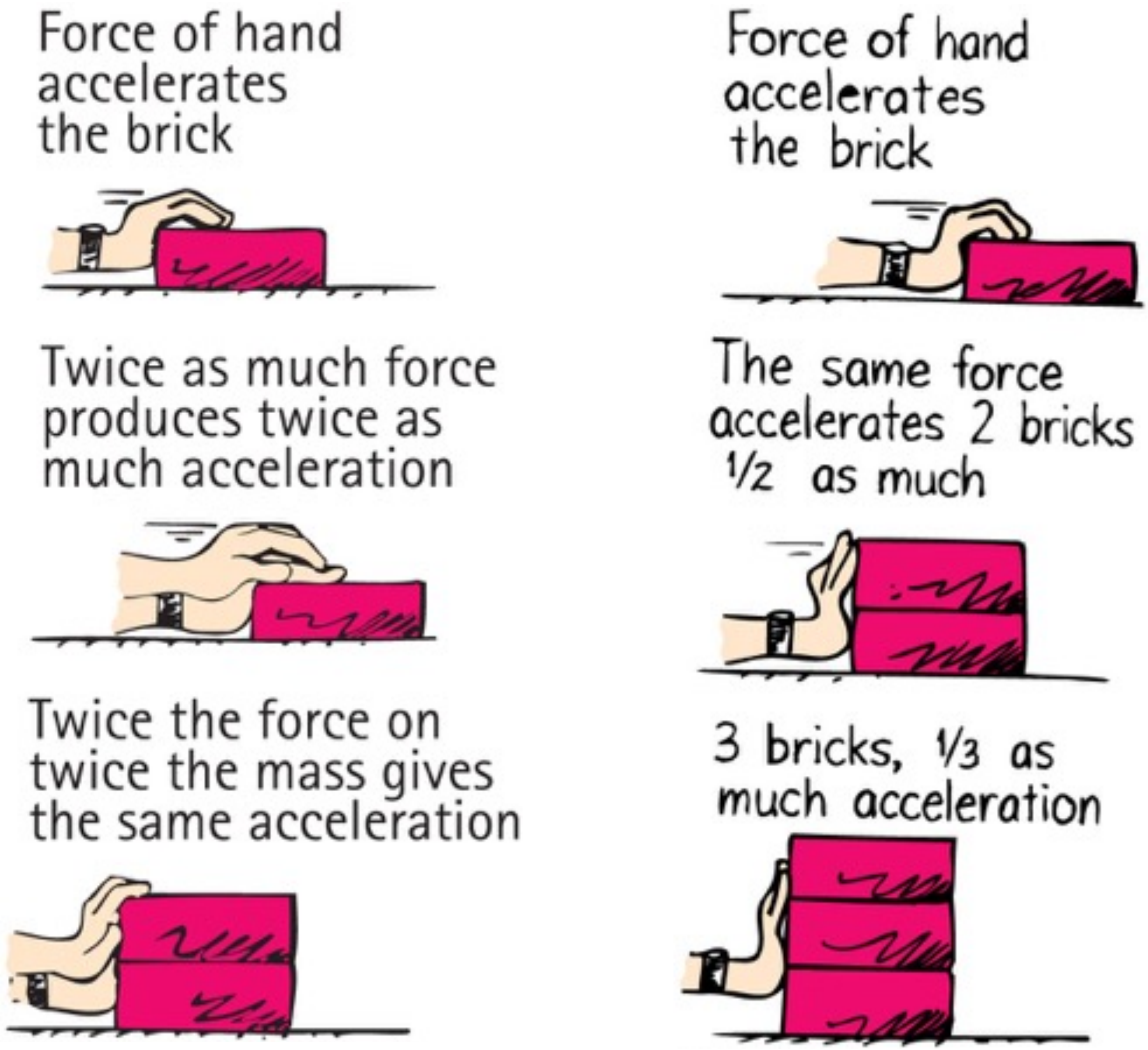
$$\text{Acceleration} = \frac{\text{net force}}{\text{mass}}$$

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



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.

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A. remains relatively the same.

B. halves.

C. **doubles.**

D. 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.*

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.

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.

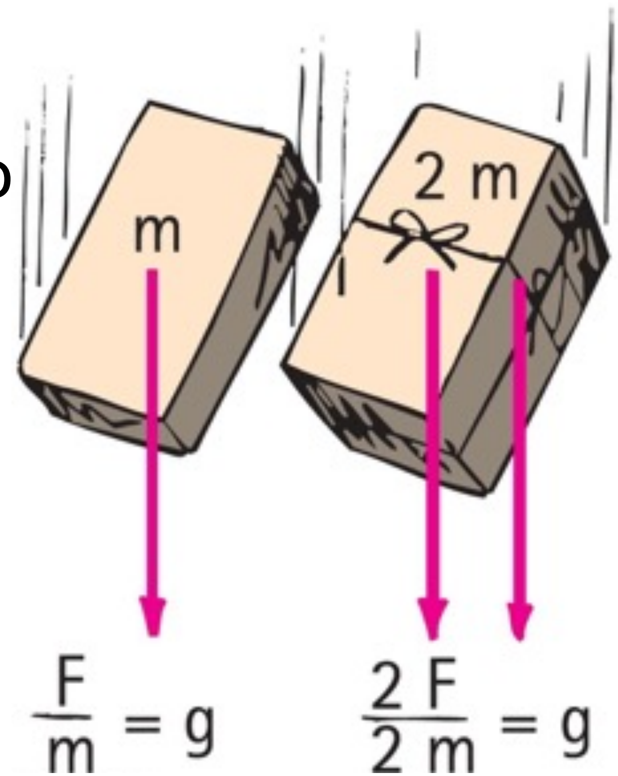
Free Fall

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.

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.

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.

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.

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A. less.

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C. more.

D. undetermined.

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.

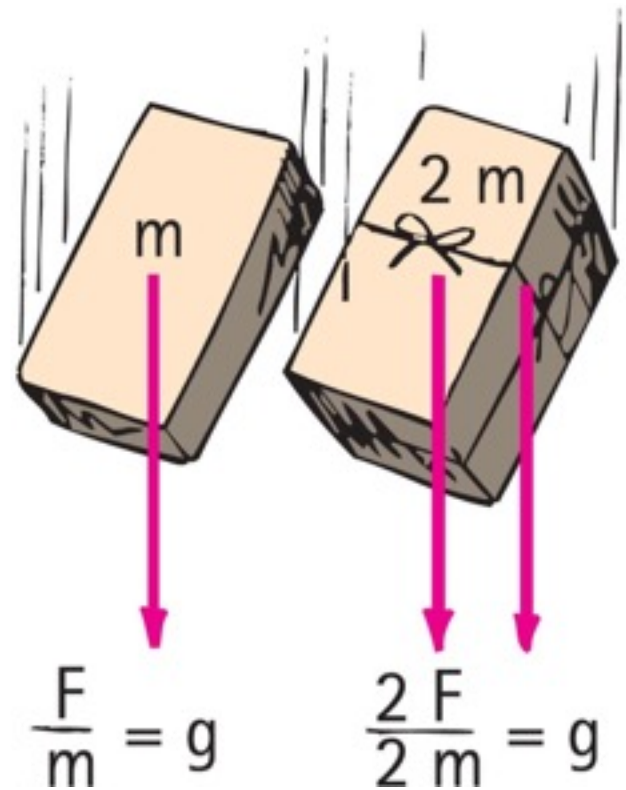
A 5-kg iron ball and a 10-kg iron ball are dropped from rest. When the free-falling 5-kg ball reaches a speed of 10 m/s, the speed of the free-falling 10-kg ball is

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

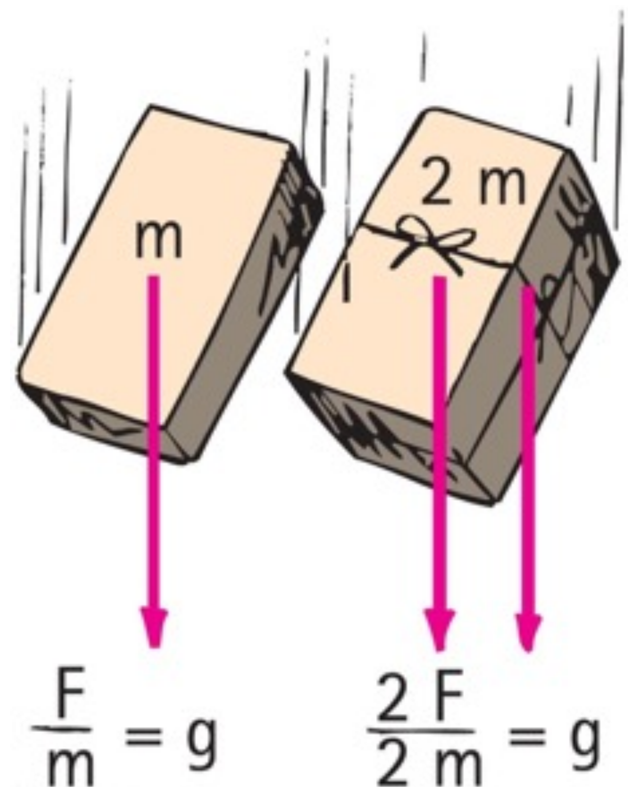
When acceleration of fall is less than *g*, non-free fall

- 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
  - ⇒ No acceleration
  - ⇒ 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.

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.

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.

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.

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.

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

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

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

A. increases.

B. decreases.

C. remains the same.

D. Not enough information.

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.

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.

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.

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.

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.

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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 heavier person has a greater downward force than the lighter person.
- The heavier person 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.

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.

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.

Chapter 4 Problems

6. Leroy, who has a mass of 100 kg, is skateboarding at 9.0 m/s when he smacks into a brick wall and comes to a dead stop in 0.2 s.

a. Show that his deceleration is 45 m/s^2.

$a = (v_{final} - v_{initial}) / (t_{final} - t_{initial}) = -9\ m/s / 0.2s =$ **$-45\ m/s^2$**

b. Show that the force of impact is 4500 N. (ouch!!)

$F = ma = 100kg \times -45\ m/s^2 = 4500\ kg\ m/s^2 =$ **-4500 N**

Summary of Terms

- **Friction** The resistive force that opposes the motion or attempted motion of an object either past another object with which it is in contact or through a fluid.
- **Mass** The quantity of matter in an object. More specifically, it is the measure of the inertia or sluggishness that an object exhibits in response to any effort made to start it, stop it, deflect it, or change in anyway its state of motion.
- **Weight** The force due to gravity on an object.
- **Kilogram** The fundamental SI unit of mass. One kilogram (symbol kg) is the mass of 1 liter (1 L) of water at 4°C.
- **Newton** The SI unit of force. One newton (symbol N) is the force that will give an object of mass 1 kg an acceleration of 1 m/s2.
- **Volume** The quantity of space an object occupies.

Summary of Terms

- **Newton's second law** - The acceleration of an object is directly proportional to the net force acting on the object, is in the direction of the net force, and is inversely proportional to the mass of the object.
- **Force -** Any influence that can cause an object to be accelerated, measured in Newtons (or in pounds, in the English system).
- **Free fall -** Motion under the influence of gravitational pull only.
- **Terminal speed -** The speed at which the acceleration of a falling object terminates because air resistance balances its weight. When direction is specified, then we speak **of terminal velocity.**

Homework

- Read Chapter 4 in Detail.
- Do Ranking 2
- Do Exercises 2, 8, 15
- Do Problem 4

Homework due: June 04