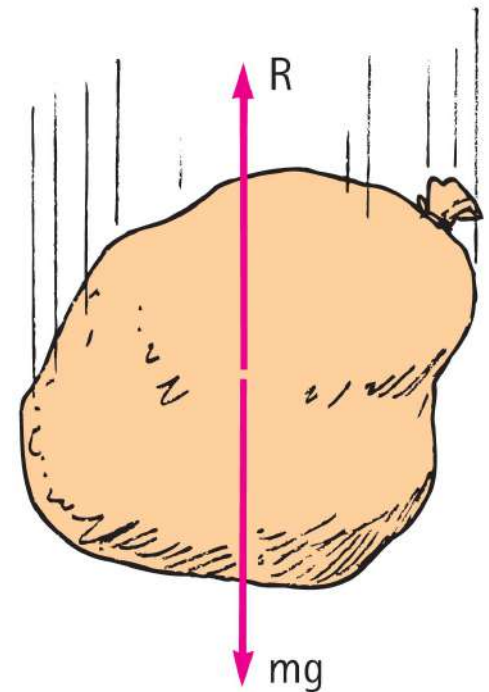


Nonfree Fall

- When an object falls downward through the air it experiences two forces:
 1. force of gravity $w = mg$ pulling it *downward*.
 2. air drag force R acting *upward*.



Nonfree Fall, Continued

- The condition of nonfree fall...
 1. ...occurs when air resistance is nonnegligible (it cannot be ignored).
 2. ...is a result of objects running into particles of the fluid (air or water) as they fall.
 3. ...depends on two things:
 - speed and
 - frontal surface area.

What affects air resistance

1. How speed v affects air resistance:

→ NO speedno air resistance

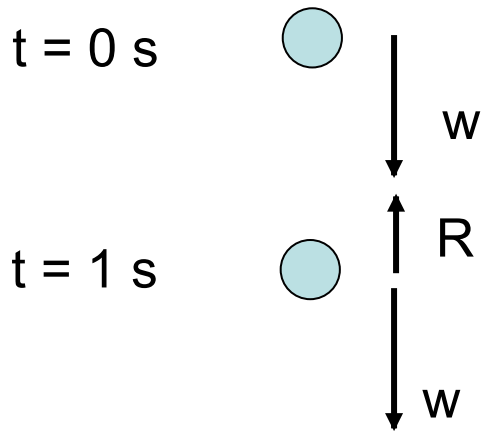
→ Air resistance increases with increasing v .

2. How surface area SA affects air resistance:

→ Air resistance increases with increasing SA .

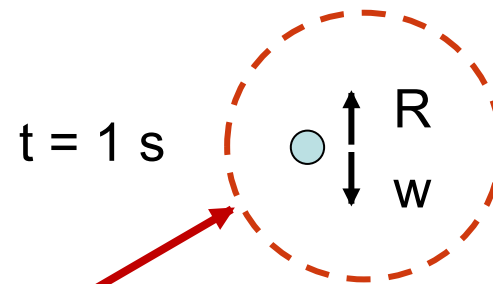
A heavy ball and a light ball dropped in air at $t = 0$ s.

heavy



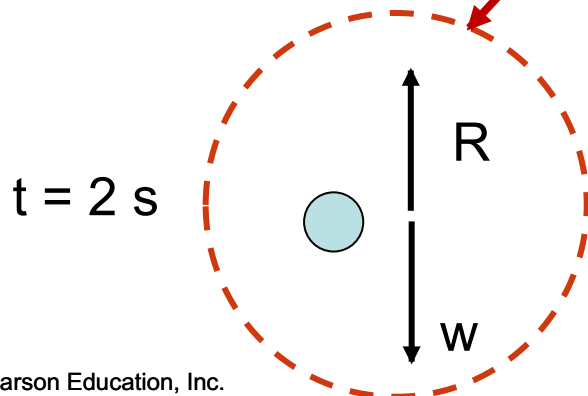
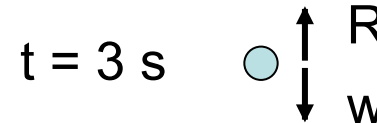
Why is the heavy ball still accelerating after 1 s?

light



Why does the light ball stop accelerating after 1 s?

Terminal velocity



Notice in previous slide:

When $R = w$, what is the net force? 0

When $R = w$, what is the acceleration? 0

Which ball takes longer time for its R to equal w ? heavy

Why? It weighs more

Which ball accelerates for a longer time? heavy

Why do heavier objects fall faster? Accelerate for a longer time.

Each ball reaches a different final speed.

This speed is called its *terminal velocity* (or speed).

After that, the ball falls at a constant speed.

Acceleration and speed during nonfree fall:

Why is there no air resistance R at $t = 0$ s? $v = 0$

At $t = 0$ s, what is the only force acting on the balls? gravity

At $t = 0$ s, why is the acceleration = 9.8 m/s^2 ? Free fall

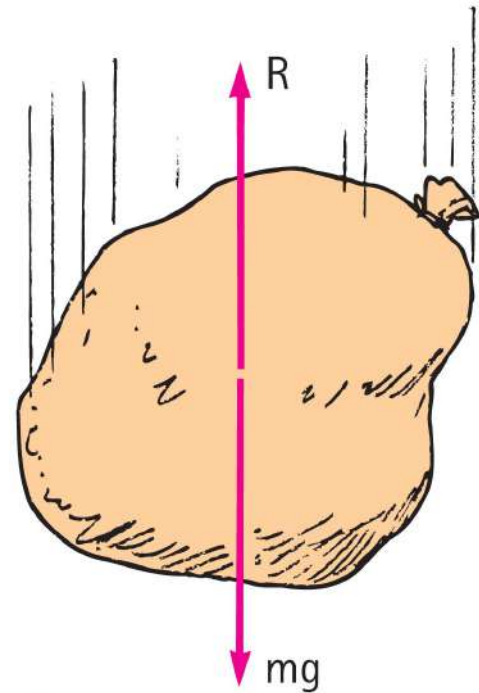
What is the acceleration at terminal velocity? 0

Does acceleration increase or decrease as the ball falls? decrease

Does speed increase or decrease as the ball falls? increase

Nonfree Fall, Continued-1

- When the object is moving fast enough so that air resistance builds up to equal the force of gravity.
- Then no net force
 - No acceleration
 - Velocity does not change



Nonfree Fall, Continued-2

- 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.

Nonfree Fall—Example

- A skydiver in fall after jumping from a plane.
- Weight and air resistance act on the falling object.
- 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.

Nonfree 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.

Nonfree 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 .

Comment:

Acceleration of a nonfree fall is always less than g .

Acceleration will actually be $(20 \text{ N} - 5 \text{ N})/2 \text{ kg} = 7.5 \text{ m/s}^2$.

Nonfree Fall

CHECK YOUR NEIGHBOR, Continued

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.

Nonfree Fall

CHECK YOUR ANSWER, Continued

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

B. 50 N.

Explanation:

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

Nonfree Fall

CHECK YOUR NEIGHBOR, Continued-1

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

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



Nonfree Fall

CHECK YOUR ANSWER, Continued-1

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

A. increases.

Nonfree Fall

CHECK YOUR NEIGHBOR, Continued-2

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.



Nonfree Fall

CHECK YOUR ANSWER, Continued-2

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

B. decreases.

Nonfree Fall

CHECK YOUR NEIGHBOR, Continued-3

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.



Nonfree Fall

CHECK YOUR ANSWER, Continued-3

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

B. decreases.

Comment:

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

Nonfree Fall

CHECK YOUR NEIGHBOR, Continued-4

Consider a heavy and a 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.

Nonfree Fall

CHECK YOUR ANSWER, Continued-4

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

B. The heavy person

Explanation:

They both have the same drag force (for the same speed).

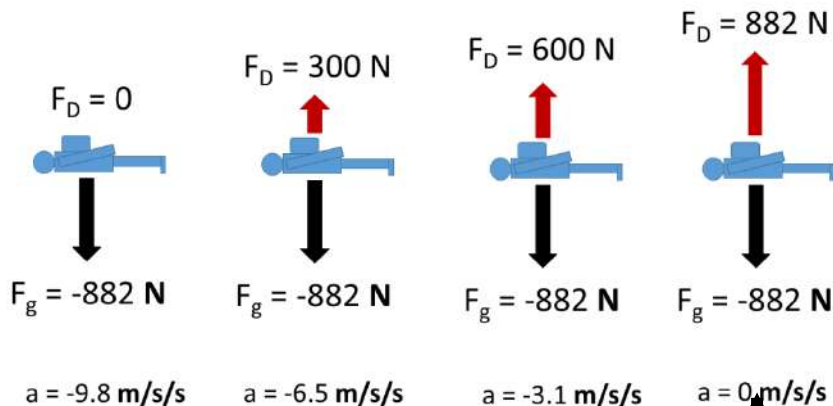
The heavier person has a greater downward force than the lighter person.

The heavier one has to drop farther to receive a drag force equal to the downward force, and so has a higher terminal velocity.

How does a parachute help?

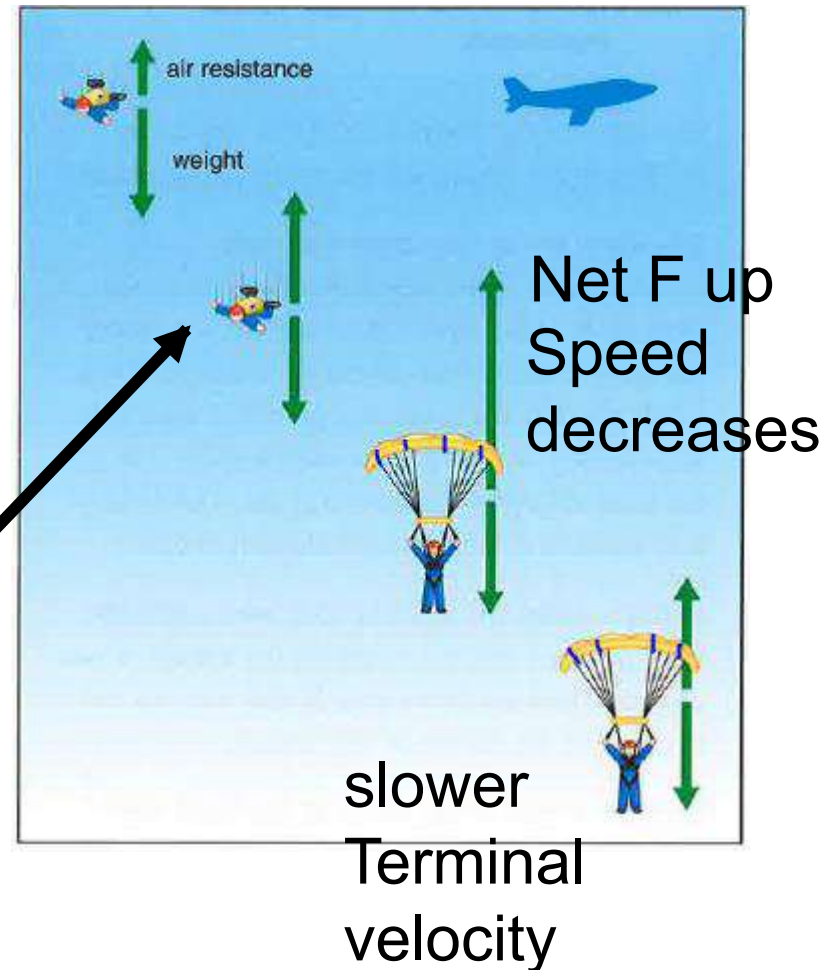
No parachute:

Mass = 90 kg Weight = 882 N



Fast
Terminal
velocity

Parachute:



Free Fall Versus Nonfree Fall

- Coin and feather fall while air is 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.



Nonfree Fall

CHECK YOUR NEIGHBOR, Continued-5

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.

Nonfree Fall

CHECK YOUR ANSWER, Continued-5

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

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

Free Fall Versus Nonfree Fall, Continued

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

