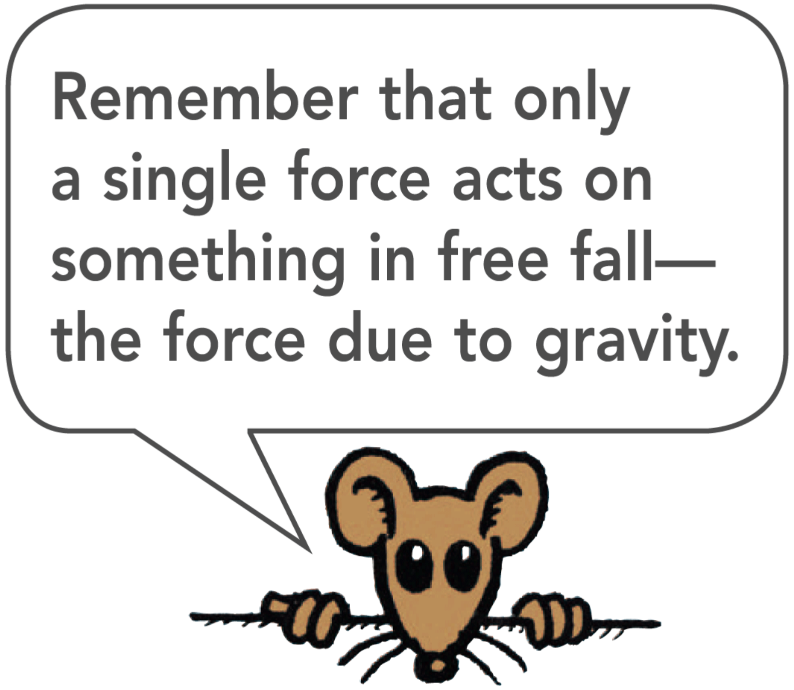
6.6 Free Fall Explained

All freely falling objects fall with the same acceleration because the net force on an object is only its weight, and the ratio of weight to mass is the same for all objects.

6.6 Free Fall Explained

Galileo showed that falling objects accelerate equally, regardless of their masses.

- This is *strictly* true if air resistance is negligible, that is, if the objects are in free fall.
- It is *approximately* true when air resistance is very small compared with the mass of the falling object.



6.6 Free Fall Explained

Galileo argued that a 10-kg cannonball and a 1-kg stone strike the ground at practically the same time.

This experiment demolished the Aristotelian idea that an object that weighs ten times as much as another should fall ten times faster than the lighter object.

6.6 Free Fall Explained

Recall that mass (a quantity of matter) and weight (the force due to gravity) are proportional.

- A 10-kg cannonball experiences 10 times as much gravitational force (weight) as a 1-kg stone.
- Newton's second law tells us to consider the mass as well.
- Ten times as much force acting on ten times as much mass produces the same acceleration.

6.6 Free Fall Explained

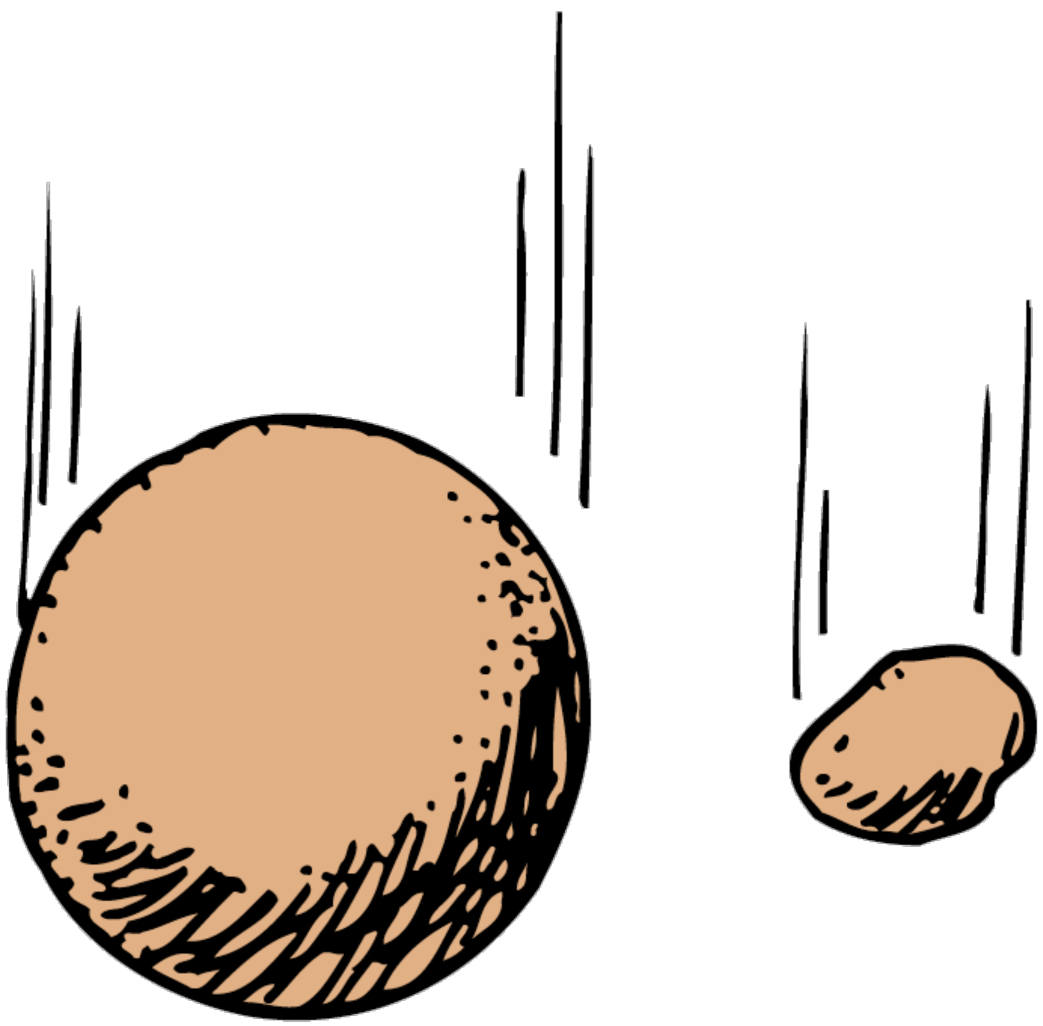
F stands for the force (weight) acting on the cannonball, and *m* stands for the correspondingly large mass of the cannonball. The small *F* and *m* stand for the weight and mass of the stone.

- The *ratio* of weight to mass is the same for these or any objects.
- All freely falling objects undergo the same acceleration at the same place on Earth.

$$\frac{F}{m} = \frac{\mathbf{F}}{\mathbf{m}}$$

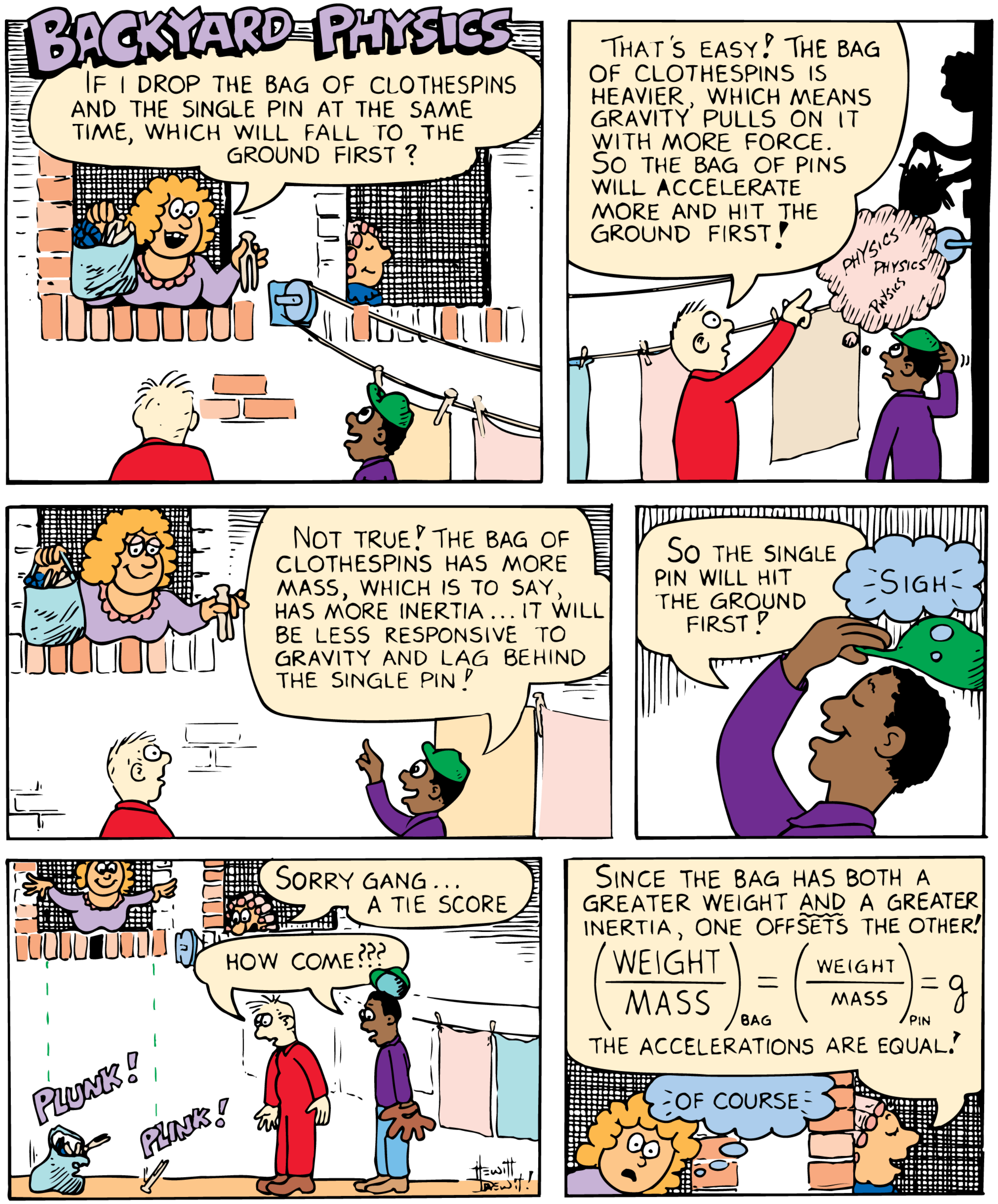
6.6 Free Fall Explained

The ratio of weight (F) to mass (m) is the same for the 10-kg cannonball and the 1-kg stone.



$$\frac{F}{m} = \frac{F}{m} = g$$

6.6 Free Fall Explained



6.6 Free Fall Explained

The weight of a 1-kg stone is 10 N at Earth's surface. Using Newton's second law, the acceleration of the stone is

$$a = \frac{F}{m} = \frac{\text{weight}}{m} = \frac{10\ \text{N}}{1\ \text{kg}} = \frac{10\ \text{kg·m/s}^2}{1\ \text{kg}} = 10\ \text{m/s}^2 = g$$

The weight of a 10-kg cannonball is 100 N at Earth's surface and the acceleration of the cannonball is

$$a = \frac{F}{m} = \frac{\text{weight}}{m} = \frac{100\ \text{N}}{10\ \text{kg}} = \frac{100\ \text{kg·m/s}^2}{10\ \text{kg}} = 10\ \text{m/s}^2 = g$$

6.6 Free Fall Explained

CONCEPT CHECK

Why do all freely falling objects fall with the same acceleration?

6.7 Falling and Air Resistance

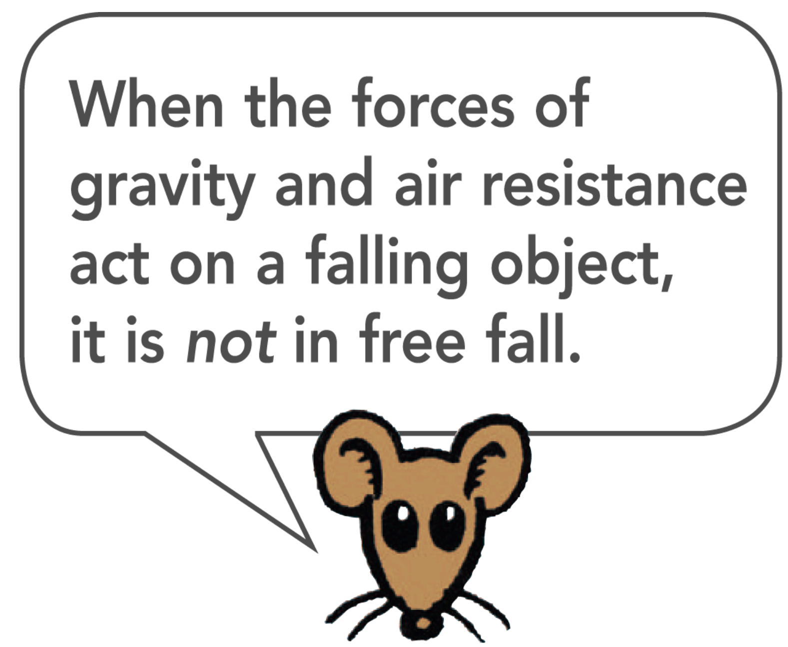
The air resistance force an object experiences depends on the object's speed and area.

6.7 Falling and Air Resistance

A feather and a coin fall with equal accelerations in a vacuum, but very unequally in the presence of air.

When falling in air, the coin falls quickly while the feather flutters to the ground.

The force due to air resistance diminishes the net force acting on the falling objects.



6.7 Falling and Air Resistance

Speed and Area

You experience the force due to air resistance when you stick your hand out of the window of a moving car.

- If the car moves faster, the force on your hand increases.
- If instead of just your hand, you hold your physics book out the window with the large side facing forward, the air resistance force is much larger than on your hand at the same speed.

6.7 Falling and Air Resistance

Air resistance force ~ speed × frontal area

The expression shows that the air resistance force is directly proportional to the speed and frontal area of an object.

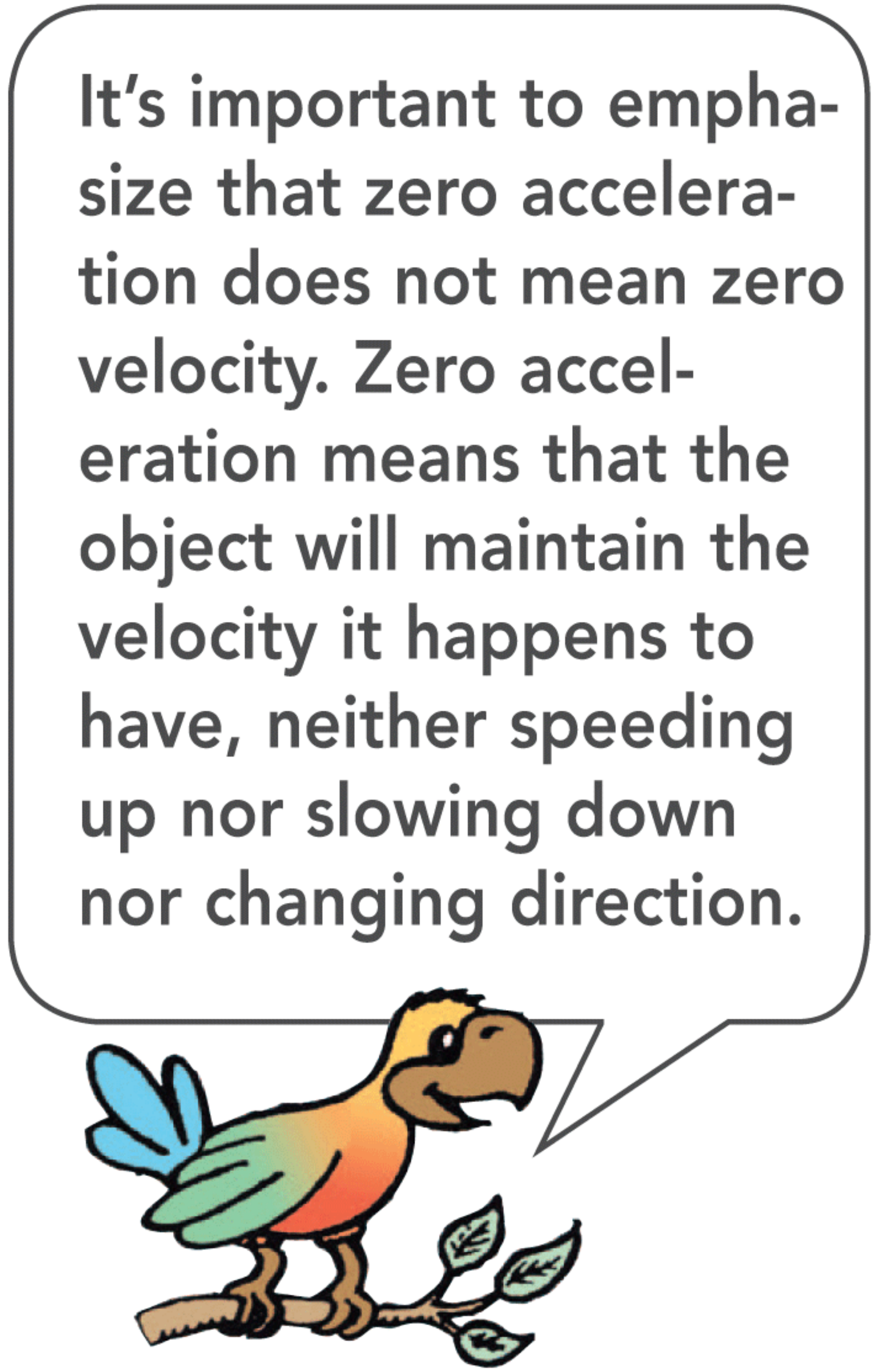
6.7 Falling and Air Resistance

Terminal Speed

Terminal speed is the speed at which the acceleration of a falling object is zero because friction balances the weight.

Terminal velocity is terminal speed together with the direction of motion.

6.7 Falling and Air Resistance



6.7 Falling and Air Resistance

Sky divers reach terminal speed when air resistance equals weight.

6.7 Falling and Air Resistance

A falling feather reaches its terminal speed quite quickly. Its area is large relative to its very small weight so air resistance has a large effect on the feather's motion.

A coin has a relatively small area compared to its weight, so the coin will have to fall faster to reach its terminal speed.

6.7 Falling and Air Resistance

The terminal speed for a sky diver varies from about 150 to 200 km/h, depending on the weight and orientation of the body.

- A heavier person will attain a greater terminal speed than a lighter person.
- Body orientation also makes a difference. More air is encountered when the body is spread out and surface area is increased.

6.7 Falling and Air Resistance

The flying squirrel increases its area by spreading out. This increases air resistance and decreases the speed of its fall.

6.7 Falling and Air Resistance

Terminal speed can be controlled by variations in body orientation.

- A heavy sky diver and a light sky diver can remain in close proximity to each other if the heavy person spreads out like a flying squirrel while the light person falls head or feet first.
- A parachute greatly increases air resistance, and cuts the terminal speed down to 15 to 25 km/h, slow enough for a safe landing.

6.7 Falling and Air Resistance

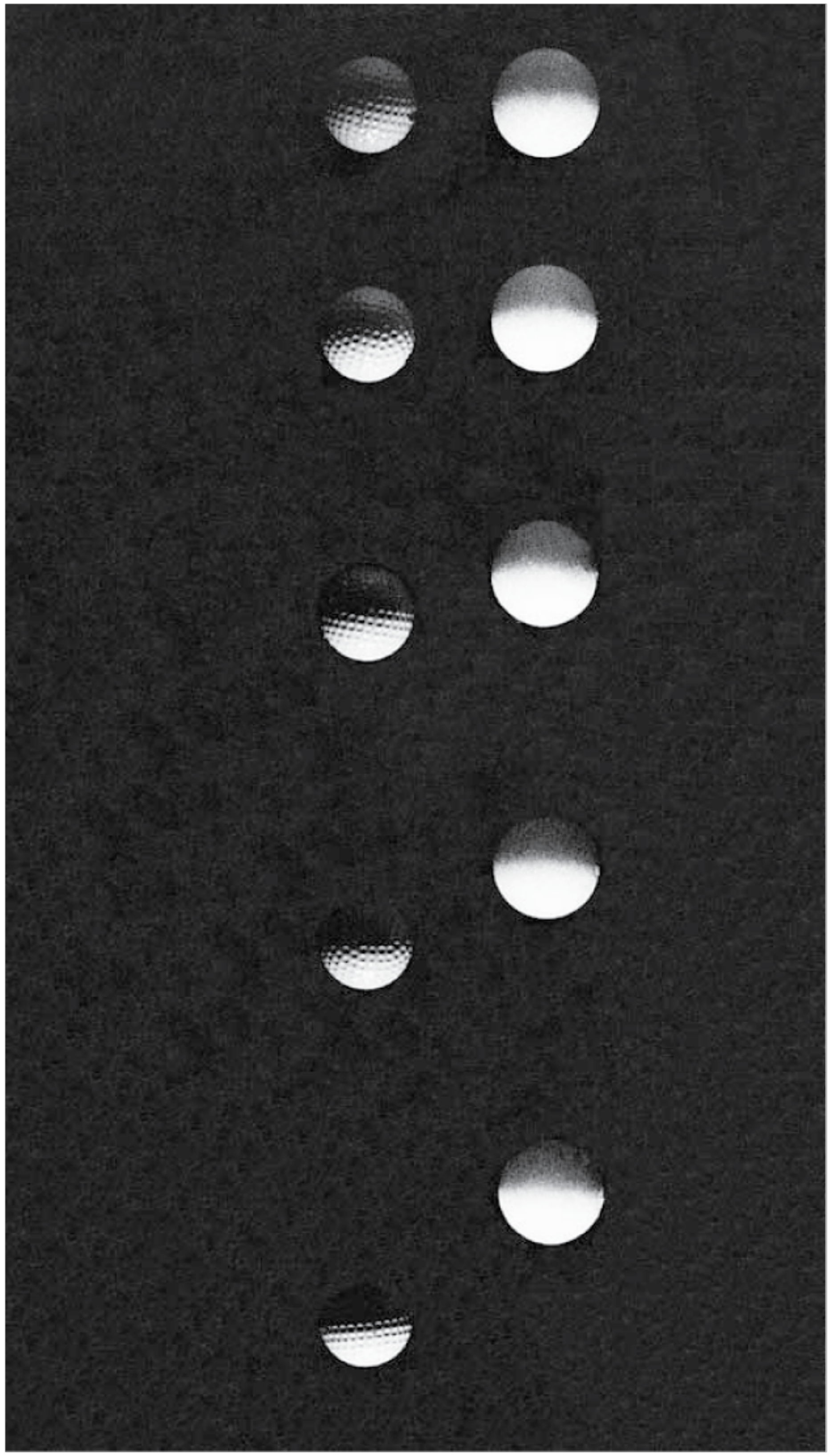
At low speeds, air resistance is often negligible, but at high speeds, it can make quite a difference.

If you hold a baseball and tennis ball at arm's length and release them at the same time, you'll see them strike the floor at the same time. But if you drop them from the top of a building, you'll notice the heavier baseball strikes the ground first.

6.7 Falling and Air Resistance

This stroboscopic photo shows a golf ball and a foam ball falling in air.

The heavier golf ball is more effective in overcoming air resistance, so its acceleration is greater.



6.7 Falling and Air Resistance

think!

Which experiences a greater air resistance force, a falling piece of paper or a falling elephant?

6.7 Falling and Air Resistance

think!

Which experiences a greater air resistance force, a falling piece of paper or a falling elephant?

Answer: The elephant! It has a greater frontal area and falls faster than a piece of paper—both of which mean the elephant pushes more air molecules out of the way. The *effect* of the air resistance force on each, however, is another story!

6.7 Falling and Air Resistance

think!

If a heavy person and a light person open their parachutes together at the same altitude and each wears the same size parachute, who will reach the ground first?

6.7 Falling and Air Resistance

think!

If a heavy person and a light person open their parachutes together at the same altitude and each wears the same size parachute, who will reach the ground first?

Answer: The heavy person will reach the ground first. Like a feather, the light person reaches terminal speed sooner, while the heavy person continues to accelerate until a greater terminal speed is reached.

6.7 Falling and Air Resistance

CONCEPT CHECK

What factors determine the air resistance force on an object?

Assessment Questions

6. The reason a 20-kg rock falls no faster than a 10-kg rock in free fall is that
   a. air resistance is negligible.
   b. the force of gravity on both is the same.
   c. their speeds are the same.
   d. the force/mass ratio is the same.

Assessment Questions

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   a. air resistance is negligible.
   b. the force of gravity on both is the same.
   c. their speeds are the same.
   d. the force/mass ratio is the same.

Answer: D

Assessment Questions

7. Kevin and Suzanne go sky diving. Kevin is heavier than Suzanne, but both use the same size parachute. Kevin has a greater terminal speed compared with Suzanne because
   a. he has to fall faster for air resistance to match his weight.
   b. gravity acts on him more.
   c. he has greater air resistance.
   d. he has weaker terminal velocity.

Assessment Questions

7. Kevin and Suzanne go sky diving. Kevin is heavier than Suzanne, but both use the same size parachute. Kevin has a greater terminal speed compared with Suzanne because
   a. he has to fall faster for air resistance to match his weight.
   b. gravity acts on him more.
   c. he has greater air resistance.
   d. he has weaker terminal velocity.

Answer: A