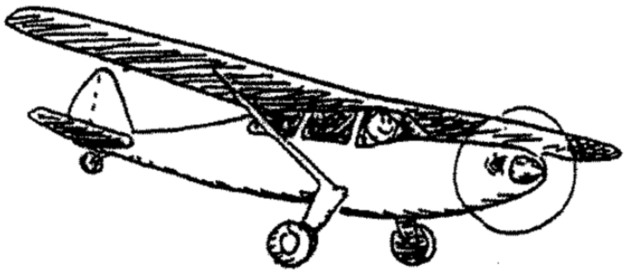
Next Time Question

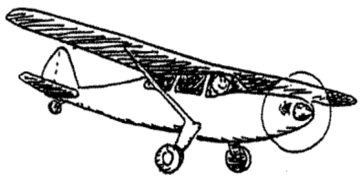


An airplane makes a straight back-and-forth round trip, always at the same airspeed, between two cities. If it encounters a mild steady tailwind going, and the same steady headwind returning, will the round trip take:

1. more
2. less
3. the same time as with no wind?

Round trip distance = 2d
$t = d/v_1 + d/v_2$
(can't add denominators)

Answer: 1: The windy trip will take more time.



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2. less

3. the same time as with no wind?

E.g. Suppose the cities are 600 km apart, and the airspeed of the plane is 300 km/h (relative to still air). Then time each way with no wind is 2 hours. Roundtrip time is 4 hours.

Now consider a 100 km/h tailwind going, so groundspeed is (300 + 100) km/h. Then the time is (600 km)/(400km/h) = 1 hour and 30 minutes.
Returning groundspeed is (300 – 100) km/h, and the time is (600 km)/(200km/h) = 3 hours.
So the windy round trip takes 4.5 hours—longer than with no wind at all.

Today: Chap 4 - Newton's Second Law

Will establish a relationship between **force** (chap 2) and **acceleration** (chap. 3).

Also introduce forces that *oppose* motion: surface friction and air resistance

Mass and Weight

- Mass = measure of inertia of object. Quantity of matter in the object. Denote *m*.

  Recall: inertia measures resistance to any effort made to change its motion

- Weight = force upon an object due to gravity

In fact, <u>weight = *mg*</u>

- Often weight and mass are used interchangeably in every-day life, but in physics, there is a fundamental difference.

- Eg. In outer space, there is no gravity so everything has zero weight. But, things still have mass. Shaking an object back and forth give sense of how massive it is because you sense the inertia of it.

- Note mass is an intrinsic property of an object - eg. it doesn't depend on where it is, whereas weight does depend on location (eg less on moon than on earth…)

Standard unit for mass is kilogram, kg.

Standard unit for weight is Newton (since it's a force) (commonly, pound)

Question

A 10 kg bag of rice weighs one-sixth as much on the moon than on earth because the moon's gravity is one-sixth as much as the earth's.

If you tried to throw the bag horizontally across to a friend, is it one-sixth as easier on the moon than on earth?

No! The same horizontal force is needed, since the mass (inertia) of the bag is the same.

inertial mass = gravitational mass; it's not obvious! (but fortunately true)

from Newton to Einstein

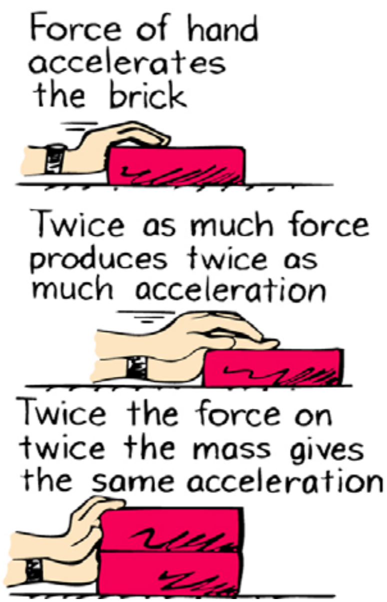
Towards Newton's Second Law of Motion…

(i) Acceleration is created by a net force

Eg. Kick a soccer ball: what forces acting, causing what motion?

First: accelerates from rest (i.e velocity from 0 to finite) due to your sudden kick.

While in air: velocity continues to change - eventually falls to the ground due to the (more gradual) force of gravity.



Acceleration ~ net force

~ means, "directly proportional to"

Twice the force on same object, gives twice acceleration

(ii) Mass resists acceleration

$$\textbf{Acceleration} \sim \frac{\mathbf{1}}{\textbf{mass}}$$

The same force applied to twice the mass gives half the acceleration

anvil revisited

Newton's Second Law

Puts (i) and (ii) together:

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.

$$a = \frac{Fnet}{m}$$

Often stated as $F_{net} = ma$

Note about direction:

An object accelerates in the direction of the net force acting on it.

Eg. Drop a ball – it accelerates downward, as force of gravity pulls it down

Eg. We considered last time throwing a ball upward. When the ball is thrown upward, what is the direction of its acceleration (after leaving your hand)?

Acceleration is downward (gravity) – so the ball slows down as it rises. i.e. when force is opposite to the object's motion, it will decrease its speed.

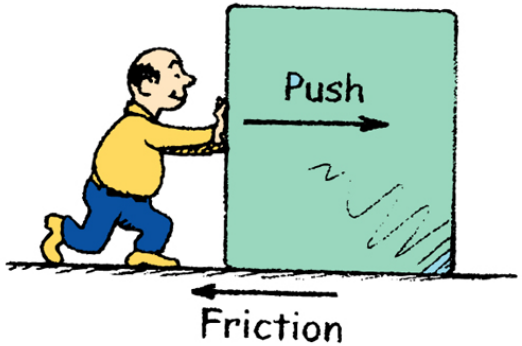
When the force is at right-angles to the object's motion (eg throw ball horizontally), the object is deflected.

Friction

- When surfaces slide or tend to slide over one another, a force of friction resists the motion. Due to irregularities (microscopic bumps, points etc) in the surfaces.

  Friction also occurs with liquids and gases – eg. air drag

Eg. Push a box across a floor, applying a small steady force. The box does not accelerate because of the force of friction – it may go at constant speed, or slow down, if you get tired and start pushing less. Only if you increase your force so that it is greater than the frictional force, will the box accelerate (speed up).



• The size of the friction force between solid surfaces does not depend on speed; nor, interestingly, on the area of contact. It does depend on the object's weight.

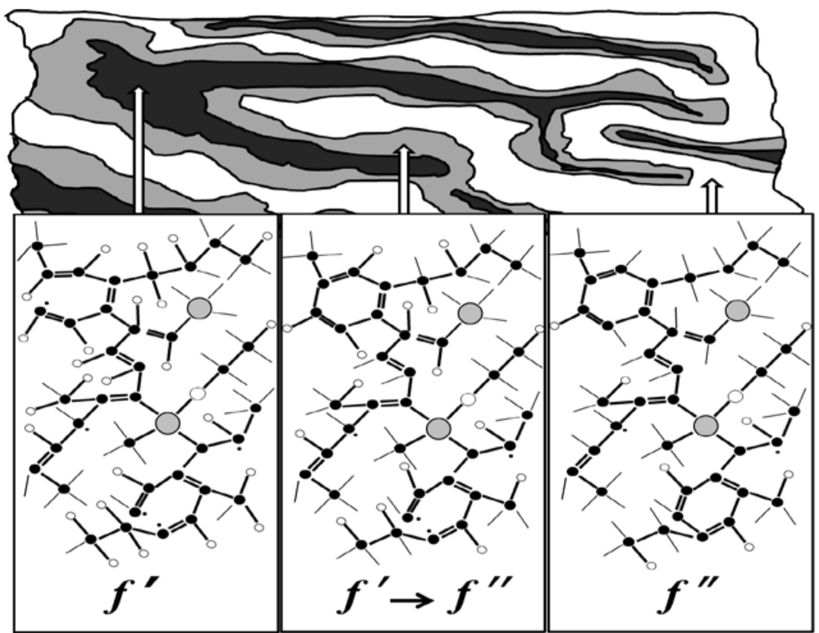
• Air drag does depend on contact surface area and speed (see more soon).

Exactly how friction works is still an active research area today! i.e. tribology.

Solid State Magnetic Resonance Investigation of the Thermally Induced Structural Evolution of Silicon Oxide-Doped Hydrogenated Amorphous Carbon

Jing Peng[a,b], Anastasiia Sergiienko[a], Filippo Mangolini[c], P. E. Stallworth[a], Steve Greenbaum[a,b] and Robert W. Carpick[d]
[a]Physics Department, Hunter College, New York, New York 10065
[b]Chemistry Program, The Graduate Center of City University of New York
[c]Institute of Functional Surfaces, School of Mechanical Engineering, University of Leeds, Leeds, LS2 9JT, UK
[d]Department of Mechanical Engineering and Applied Mechanics, University of Pennsylvania, Philadelphia, PA 19104

Structural Model for distribution of Carbon, Silicon, Hydrogen, and broken chemical bonds



Consider now the box at rest.

- Just sitting there, there is no friction.

- If push it, but not hard enough, so it stays at rest, then the size of the friction force must exactly equal (cancel) the size of the pushing force. Why?

zero acceleration means zero net force

Push a bit harder but it still won’t move, the friction increases to exactly oppose it. Called “**static friction**” since nothing moves.

- There is a max. static friction force between any two objects, such that if your push is just greater than this, it will slide.

- Then, while it is sliding as you are pushing it, the friction becomes “**sliding friction**” (which is actually less than the friction that was just built up before it started moving).

- That static friction > sliding friction is important in anti-lock braking systems in cars (see your book for more on this)

F (friction) is proportional to the normal contact force

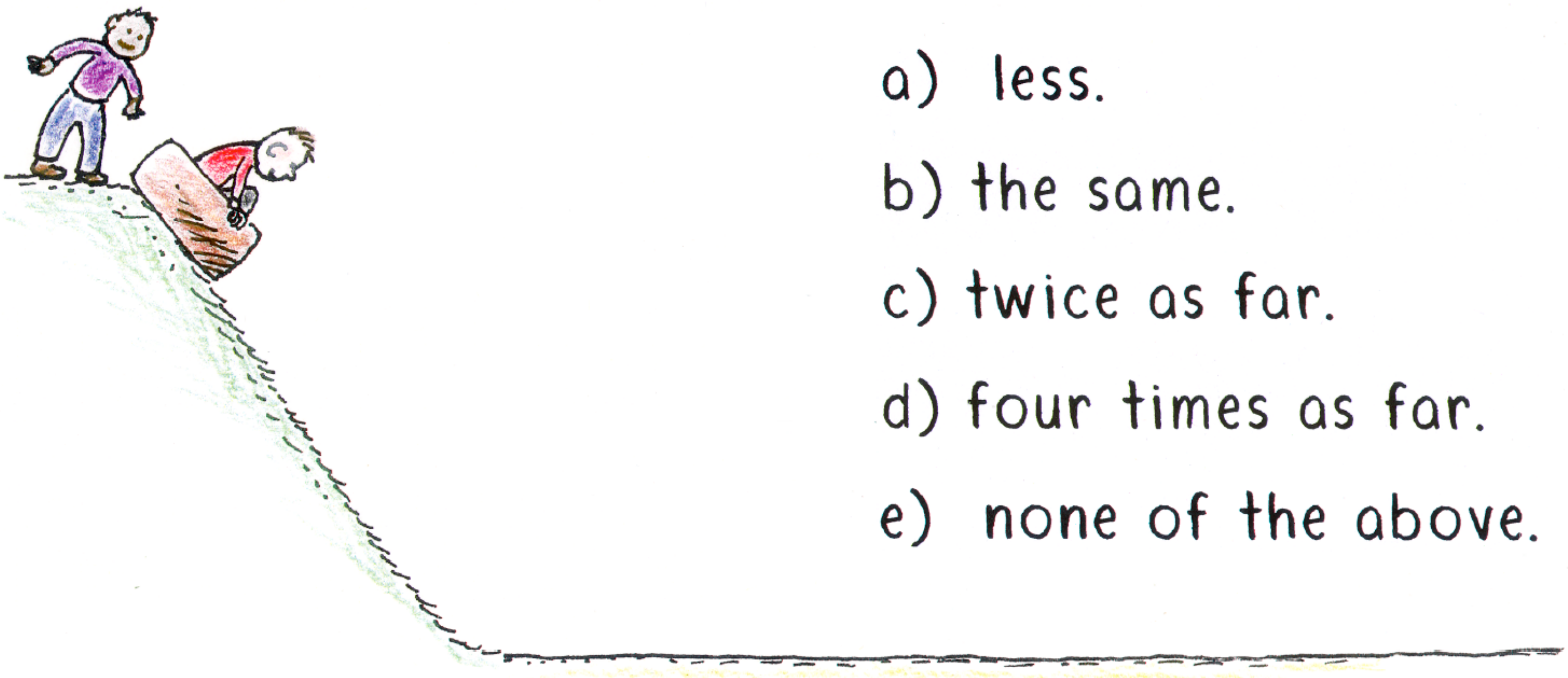
For object on a horizontal surface, the normal force is the weight; the proportionality constant depends on the nature of the surfaces in contact, and decreases when there is relative motion of the surfaces (i.e. sliding).

Question: Why doesn’t the frictional force change when you change the contact area?

It’s proportional to the weight per area times the area

DEMO

Little Larry slides down an icy grass slope in a cardboard box and skids to a stop across the flat ground. If Larry's friend were also in the box, giving it twice the mass and starting from the same height, the skidding distance would be



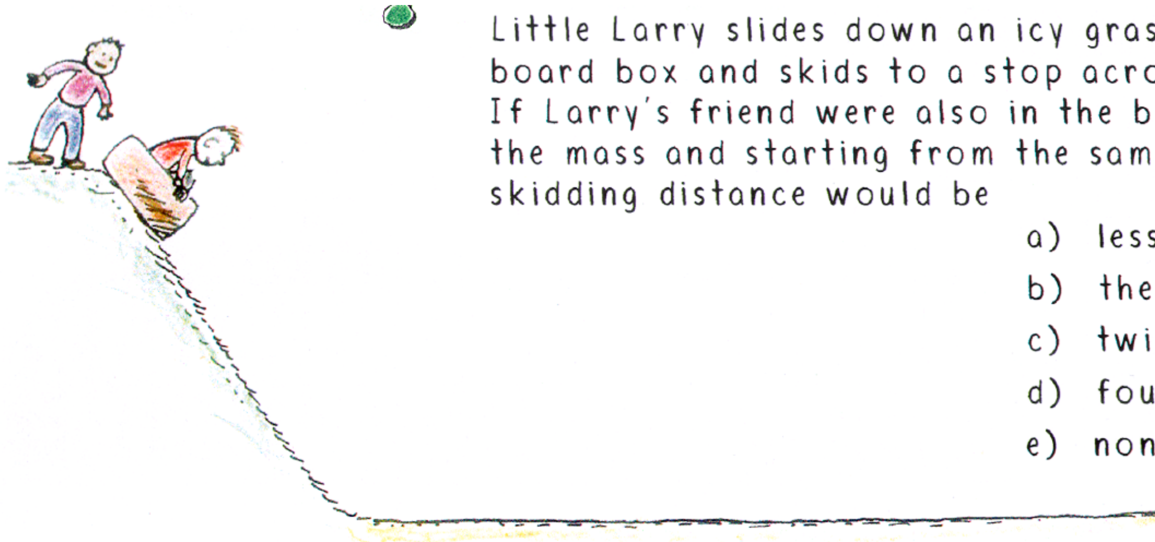
a) less.

b) the same.

c) twice as far.

d) four times as far.

e) none of the above.



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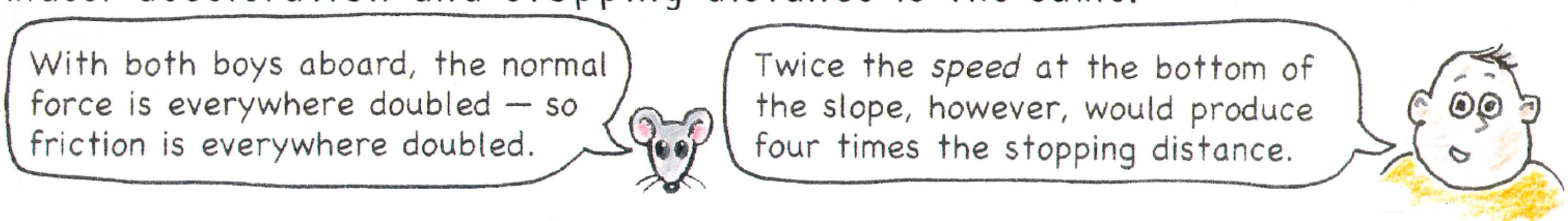
Answer: b

Twice the mass means twice the normal force and, hence, twice the friction—both on the slope and on the level ground. So on the slope, with both gravity and friction proportional to mass, acceleration is the same and the speed at the bottom is the same. Starting with the same speed across the flat ground, with frictional force proportional to mass, deceleration and stopping distance is the same.



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$a = F/m = (120\ 000\ \text{N})/(30\ 000\ \text{kg}) = 4\ \text{m/s}^2$

Free-fall: when $a = g$

Recall last time: when the force of gravity is the only force (negligible air resistance), then the object is in "free-fall".

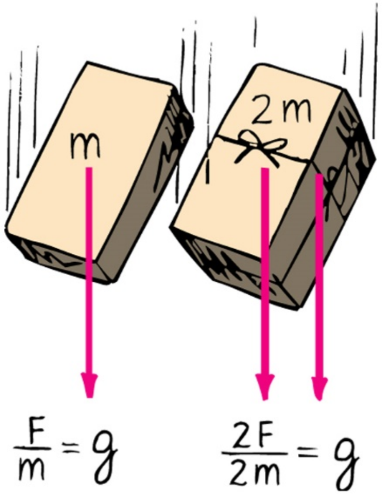
Question

Since weight = mg = force of gravity on an object, heavier objects experience more gravitational force – so why don't they fall faster than lighter ones ?

Answer: The acceleration depends both on the force and the mass – heavier objects also have a greater inertia (resistance to acceleration), a larger mass. In fact mass cancels out of the equation:

$$a = F/m = mg/m = g$$

So all objects free-fall at the same rate, g.



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In a vacuum, a coin and feather fall side by side, at the same rate. Is it true to say that, in vacuum, equal forces of gravity act on both the coin and the feather?

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NO! They accelerate together because the ratio weight/mass for each are equal (=g)

How do things fall when there is air resistance? "nonfree fall"

A feather and a coin do *not* fall at the same rate in air because of air resistance, (a.k.a. air drag).

Let's begin with a little demo:

(i) Drop a piece of paper - as it falls, it flutters, moves sideways due to air resistance.

(ii) Crumple paper into ball – it falls faster, less air resistance because of less surface area (see more shortly)

(iii) Drop book and paper side by side – book falls faster, due to greater weight c.f. air drag

(iv) Place paper on lower surface of book and drop – they fall together.

(v) Place paper on upper surface of book and drop – what happens?? They fall together!! The book "plows through the air" leaving an air resistance free path for paper to follow.

More details…

- Newton's Laws still apply: in addition to force of gravity, have force of air drag, *R*.

- So acceleration = Net Force/mass is less than in vacuum, since

  Fnet = weight (down) – air drag (up)

  $= mg - R$

- *R* depends on

(i) the **frontal area** of the falling object – the amount of air the object must "plow"

(ii) the **speed** of the falling object – the faster, the more air molecules encountered each second

• Eg. Our paper and book demo – both had about the same frontal area, but since the weight of the paper < weight of book, the (increasing) air drag soon cancels the downward acting weight. Then the net force is zero and it no longer accelerates – it goes at constant **terminal speed** (or **terminal velocity**) after this.

On the other hand, the book continues to gain speed, until its larger weight equals R, and then it too will go at its terminal speed, higher since it accelerated for longer.

- The same idea applies to all objects falling in air eg. Skydiver, speeds up initially, and so the air drag force *R* increases. Eventually a speed is reached that *R* equals the weight, after which no more speed gain – this is terminal speed.

- Note also that effect of air drag may not be noticeable when dropped from shorter heights, since speeds gained are not as much, so air drag force is small c.f. weight.

Eg: Terminal speeds:

Skydiver ~ 200 km/h

Baseball ~ 150 km/h (or, 95 mi/h)

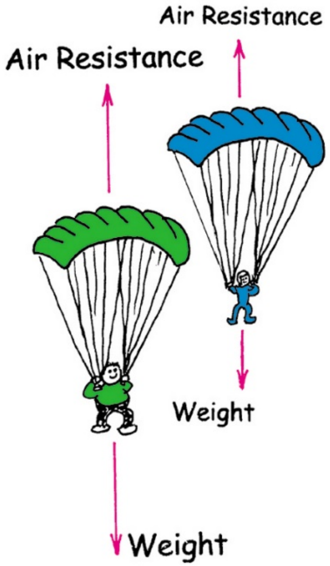
Ping-pong ball ~ 32 km/h (or, 20 mi/h)

Feather ~ few cm/s

Question: How can a skydiver decrease his terminal speed during fall?

Answer: By spreading himself out (increase frontal area)

Eg. Two parachuters, green man heavier than blue man, each with the same size of chute. Who gets to the ground first? Let's ask a series of questions:



(1)First ask, if there was no air resistance, who would get there first?

Both at the same time.

(2) They both begin to fall together in the first few moments. For which is the air drag force greater?

R depends on area – same for each, and speed – same for each. So both experience the *same drag force R*

(3) Who attains terminal velocity first? i.e. who stops accelerating first?

When *R* becomes equal to the weight, since then there is zero net force. Since blue's weight is less, blue attains terminal velocity first.

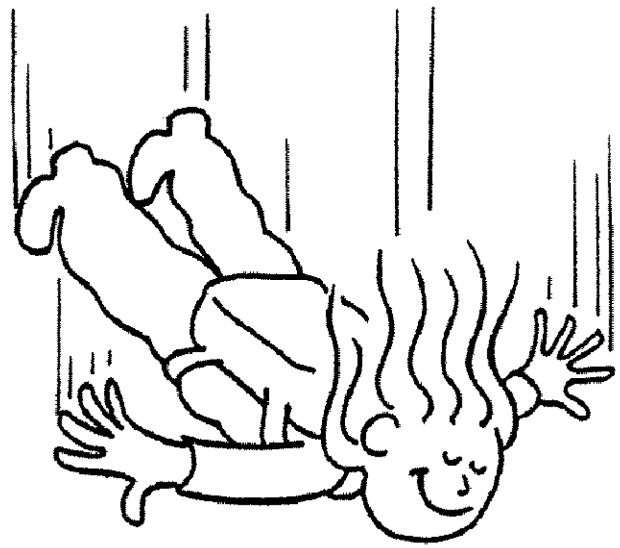
(Note that as they accelerate, *R* increases, because speed increases but after terminal speed reached, *R* is const.)

(4) Who has larger terminal velocity so who reaches ground first?

Green, he reaches his term. veloc..later, after accelerating more, so is faster…

As she falls faster and faster through the air, her acceleration

1. increases.
2. decreases.
3. remains the same.



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2. **decreases.** ✔
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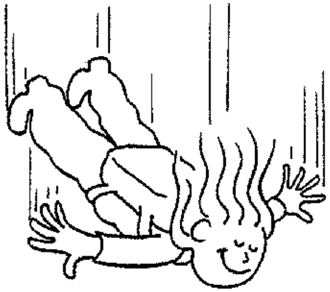


Answer: Acceleration decreases because the net force on her decreases. Net force is equal to her weight minus her air resistance, and since air resistance increases with increasing speed, net force and hence acceleration decreases. By Newton's 2nd law,

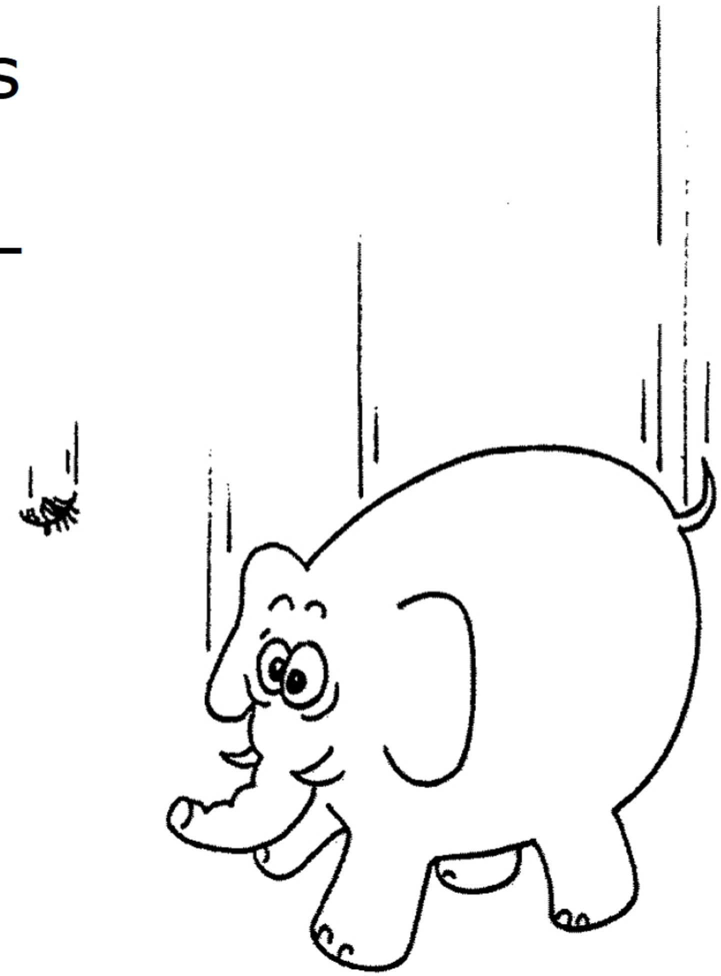
,

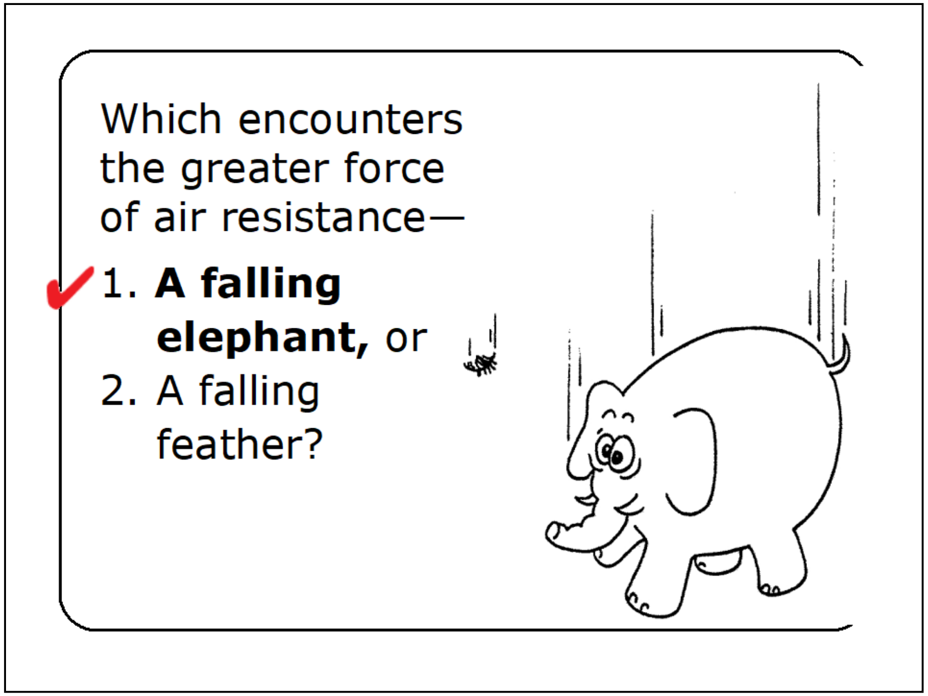
$$a = \frac{F_{\text{net}}}{m} = \frac{(mg - R)}{m}$$

where *mg* is her weight and *R* is the air resistance she encounters. As *R* increases, *a* decreases. Note that if she falls fast enough so that *R* = *mg*, *a* = 0, then with no acceleration she falls at constant velocity.

Which encounters the greater force of air resistance—

1. A falling elephant, or
2. A falling feather?

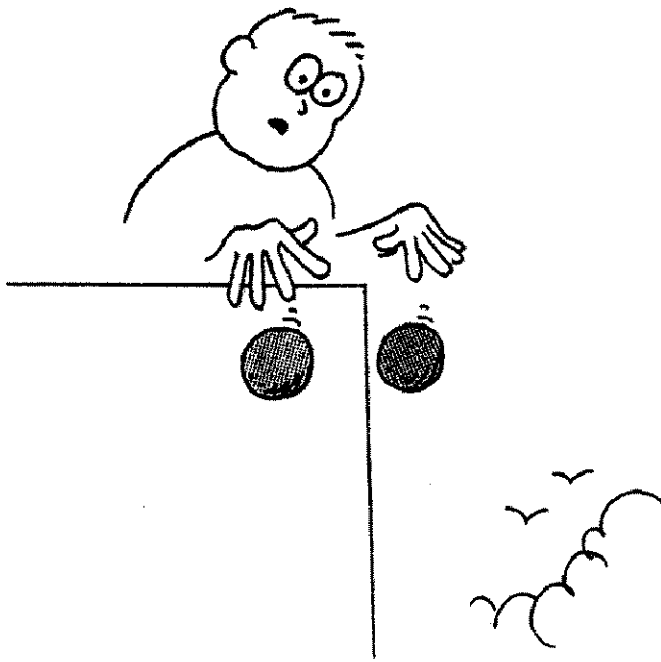




Answer: the elephant

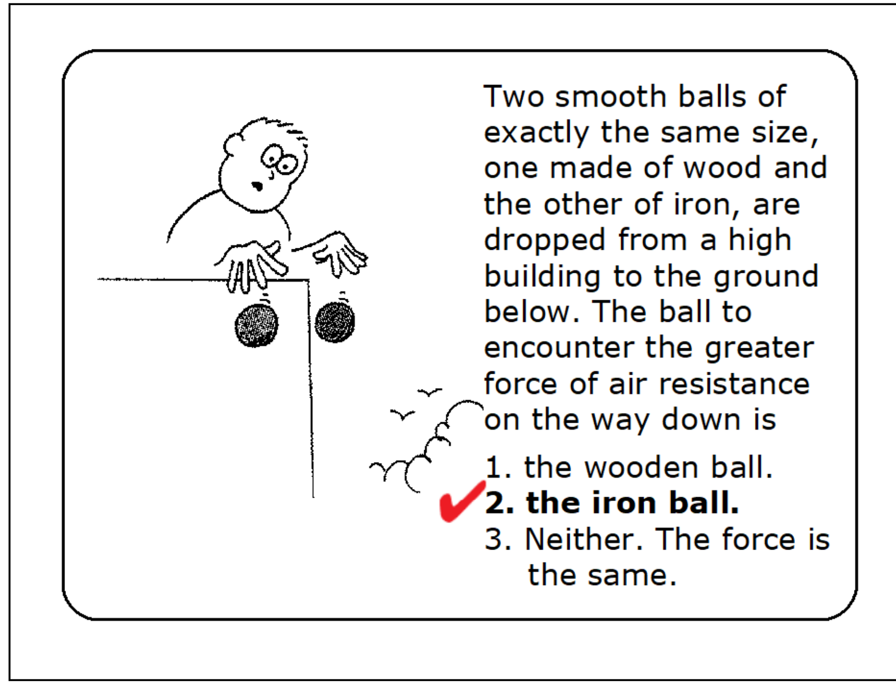
There is a greater force of air resistance on the falling elephant, which "plows through" more air than the feather in getting to the ground. The elephant encounters several newtons of air resistance, which compared to its huge weight has practically no effect on its rate of fall. Only a small fraction of a newton acts on the feather, but the effect is significant because the feather weighs only a fraction of a newton.

Remember to distinguish between a force itself and the effect it produces!



Two smooth balls of exactly the same size, one made of wood and the other of iron, are dropped from a high building to the ground below. The ball to encounter the greater force of air resistance on the way down is

1. the wooden ball.
2. the iron ball.
3. Neither. The force is the same.

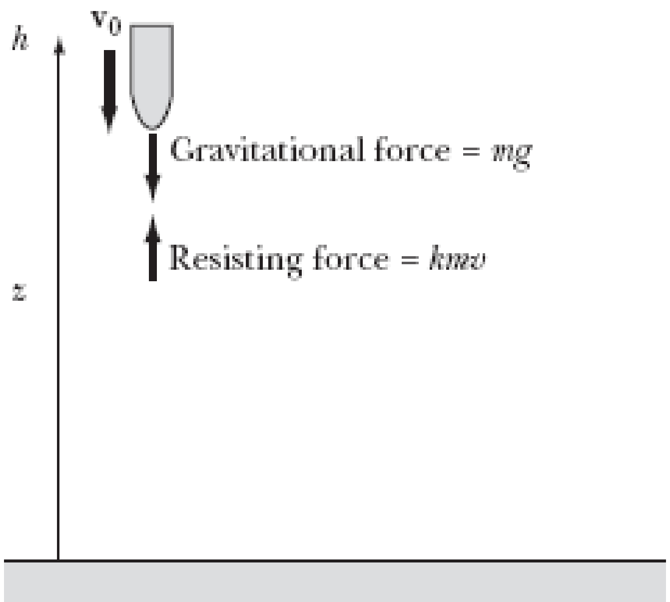


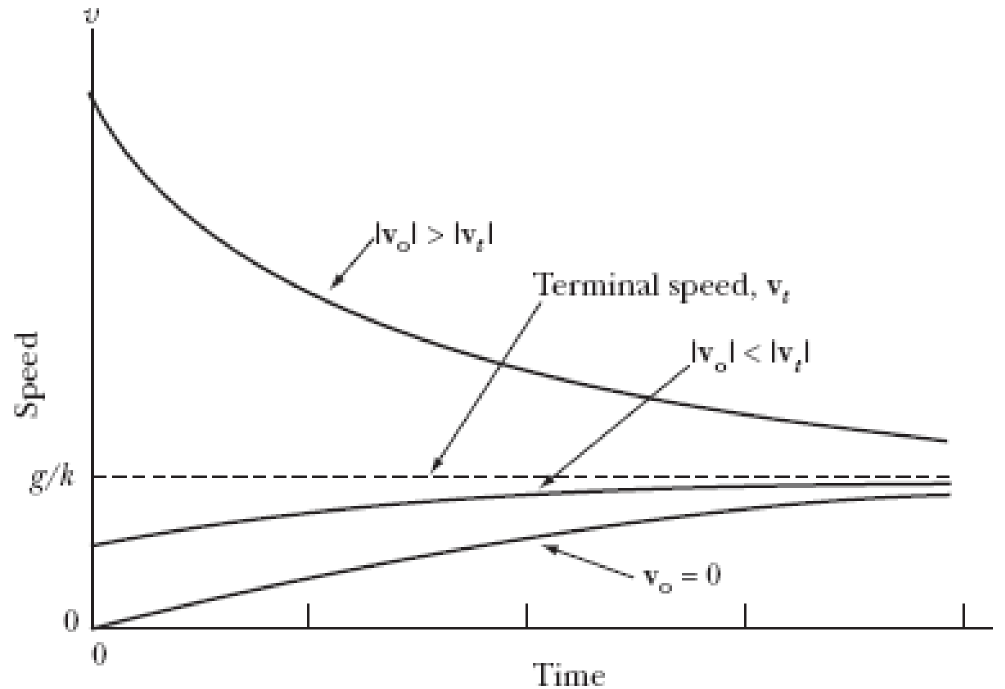
Answer: the iron ball

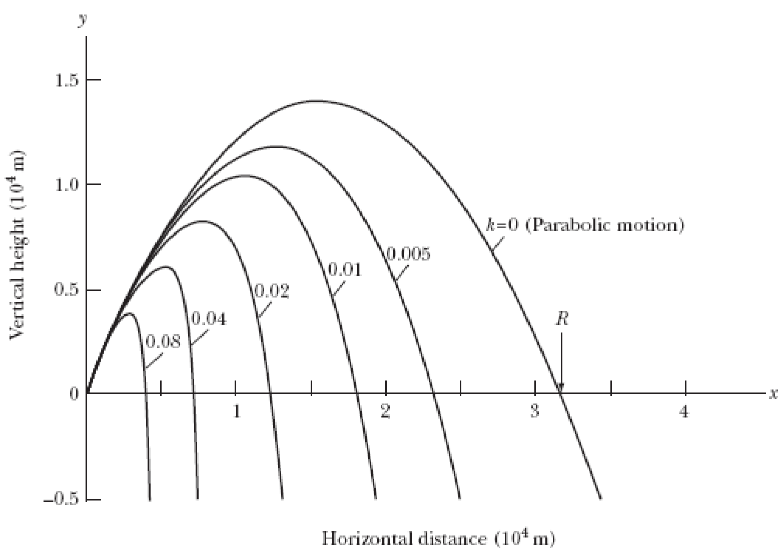
Air resistance depends on both the size and *speed* of a falling object. Both balls have the same size, but the heavier iron ball *falls faster* through the air and encounters *greater air resistance* in its fall.

Be careful to distinguish between the *amount* of air drag and the *effect* of that air drag. If the greater air drag on the faster ball is small compared to the weight of the ball, it won't be very effective in reducing acceleration. For example, 2 newtons of air drag on a 20-newton ball has less effect on fall than 1 newton of air drag on a 2-newton ball.

Snippets from Phys 335; *Classical Dynamics* (Thornton, Marion)







NEXT-TIME QUESTION

CONCEPTUAL Physics

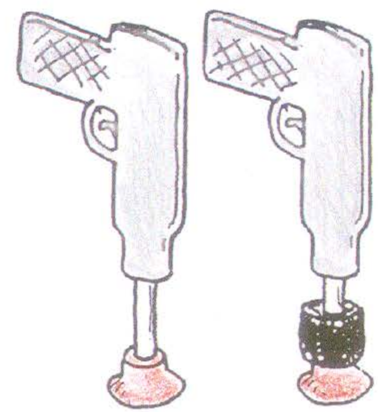
Two identical spring-loaded dart guns are simultaneously fired straight downward. One fires a regular dart; the other a weighted dart.

Which dart hits the ground first?

a) The regular dart.

b) The weighted dart.

c) It's a tie.



thanx to Dean Baird

Hewitt Drew it!

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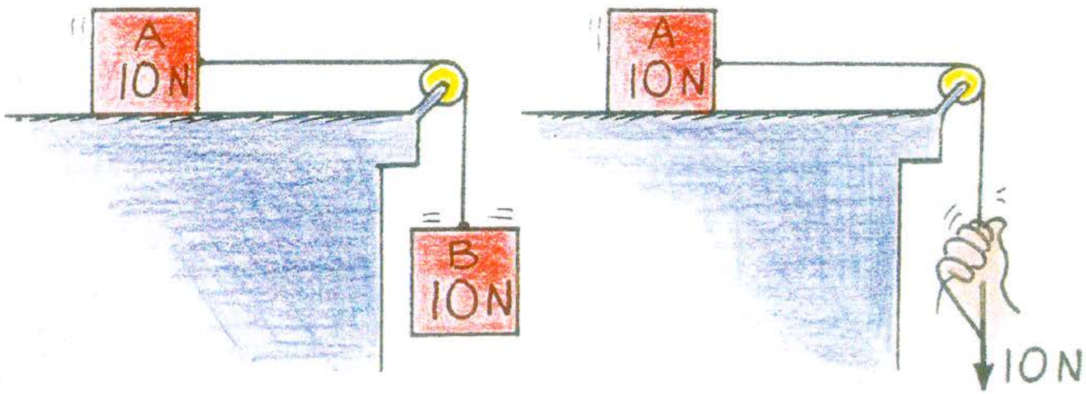

In both systems an applied force of 10 N causes Block A to accelerate. The acceleration of Block A is

a) the same in both systems.
b) greater in the one-block system.
c) greater in the two-block system.

The tension in the string is

d) the same in both systems.
e) greater in the one-block system.
f) greater in the two-block system.

Hewitt Drew it!