Question:

A student with mass M is standing on a wooden plank of mass m that is less than the mass of the student. The plank itself is resting on the frictionless surface of a frozen lake. The student then begins to walk with a speed v toward the nearby shore. What is the velocity of the plank, relative to the shore?

a. v, away from the shore
b. Less than v, away from the shore
c. Less than v, toward the shore
d. More than v, away from the shore
e. More than v, toward the shore

Answer:

The correct answer is ***d***. The problem can be analyzed using $F_{net} = ma$ or conservation of momentum. Using a momentum analysis, consider the total momentum of the system to be zero at the beginning of the problem.

$$m_{student}v_{student} + m_{plank}v_{plank} = m_{student}v_{student}' + m_{plank}v_{plank}'$$

$$M(0) + m(0) = M(v_{student}) + m(v_{plank})$$

$$v_{plank} = -\frac{M}{m}v_{student}$$

Here, the negative sign indicates that the plank is moving in a direction opposite that of the student (ie. away from the shore), and the fact that M>m means that the velocity of the plank is going to be greater than the velocity of the student.

Question:

An inelastic collision between two objects has occurred if

a. total momentum before and after the collision remains constant and there is an increase difference between initial and final kinetic energy.
b. total momentum before the collision is greater compared to after the collision and there is an decrease difference between initial and final kinetic energy.
c. both total momentum and kinetic energy remain constant.
d. total momentum before and after the collision remains constant and there is an decrease difference between initial and final kinetic energy.
e. two of the above choices are valid.

Answer:

e. **Both a and d are valid for inelastic collisions.**

Question:

A mass m is sliding along a frictionless air track with velocity v_0 in the x-direction, when it collides with and sticks to an object with mass $3m$ that was stationary. The final velocity of the two masses after the collision is:

a. $\frac{4}{3}v_0$

b. $\frac{2}{3}v_0$

c. $\frac{1}{2}v_0$

d. $\frac{1}{3}v_0$

e. $\frac{1}{4}v_0$

Answer:

The correct answer is *e*. This is an example of a perfectly inelastic collision, where the final velocity of the two-mass system can be solved using conservation of momentum:

$$m_1v_1 + m_2v_2 = (m_1 + m_2)v'$$

$$v' = \frac{m_1v_1 + m_2v_2}{(m_1 + m_2)}$$

$$v' = \frac{mv_0 + 3m(0)}{(m + 3m)} = \frac{1}{4}v_0$$

Question:

Two balls of different mass, m_1 and m_2, are pitched at the same velocity $\mathbf{v}_i$ to a baseball player, who bats each one, applying the same impulse to each ball. Which of the following quantities *must* be the same?

a. $\mathbf{p}_{1f}$ and $\mathbf{p}_{2f}$
b. $\mathbf{v}_{1f}$ and $\mathbf{v}_{2f}$
c. $\mathbf{F}_1$ and $\mathbf{F}_2$
d. $\Delta\mathbf{p}_1$ and $\Delta\mathbf{p}_2$
e. $\mathbf{a}_1$ and $\mathbf{a}_2$

Answer:

The correct answer is ***d***. Applying an identical *impulse* to each ball results in an identical *change in momentum*. By definition:

$$\textbf{Impulse} = \mathbf{F}t = m\Delta\mathbf{v} = \Delta\,\mathbf{p}$$

Answer ***a*** is not correct because the two balls have different initial momentums, and experience identical *changes* in momentum—they can't have identical final momentums.
Answer ***b*** can't be correct for a similar reason.
Answers ***c*** and ***d*** *might* be the same but may not be, depending on the Force and time of contact with each baseball.
Answer ***d*** is the only one with quantities that *must* be the same.

Question:

A soccer ball is rolling along a field with a speed $+v_{initial}$ when a student runs up and kicks the ball in the same direction that it was traveling so that it now has a greater speed in the same direction, $+v_{final}$. Your physics teacher wants you to take measurements that will allow you to calculate a rough estimate of the *impulse* applied to the ball by the student's foot. Which measurements would you want to make so that you could calculate this impulse?

I. The *distances* and *times* the ball traveled, both before and after the kick
II. The *mass* of the ball
III. The *Force* applied to the ball
IV. The *time* that the foot and the ball were in contact

a. I and II
b. I and III
c. I and IV
d. II and III
e. II and IV

Answer:

The correct answer is ***a***. By measuring the *distances* and *times* for the ball's motion we can estimate its initial and final velocities, and by measuring the mass of the ball, we'll be able to calculate the change in momentum, which is equal to the impulse applied to the ball.

These quantities are all reasonably measured: the *mass* of the ball can be measured using a balance or spring scale, and the *distance* and *time* of the ball's motion can be estimated on the field, or even recorded using a camera and analyzed frame by frame.

Impulse can also be calculated using *Force* and *time of contact*, but these are very difficult to measure on the field. The *Force* varies over time, and the time of contact is usually very short—much less than a second—so trying to get good measurements of these quantities is beyond the capabilities of most physics classroom labs.

Which of the following statements concerning momentum are correct?

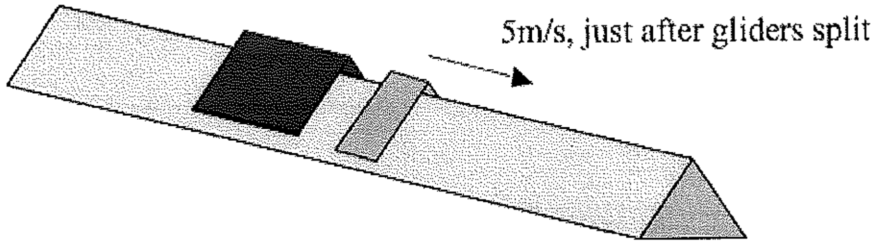
I. Two objects with the same mass can't have the same momentum.
II. As an object's velocity increases, so does its momentum.
III. When an object collides with another, its momentum will always change.

a. I only
b. II only
c. III only
d. II and III
e. I, II and III

Answer:

d.

Question:



An air track glider of mass M is built, consisting of two smaller connected gliders with a small explosive charge located between them. The glider is traveling along a frictionless rail at 2 m/s to the right when the charge is detonated, causing the smaller glider with mass $\frac{1}{4}M$, to move off to the right at 5 m/s. What is the final velocity of the second small glider?

a. 4 m/s to the left
b. 2 m/s to the left
c. 1 m/s to the left
d. 0 m/s
e. 1 m/s to the right

Answer:

The correct answer is ***e***. This is a conservation of momentum problem, in which the total momentum of the glider at the beginning of the problem is equal to the sum of the momenta of the individual gliders at the end of the problem.

$$Mv = m_1 v_1' + m_2 v_2'$$

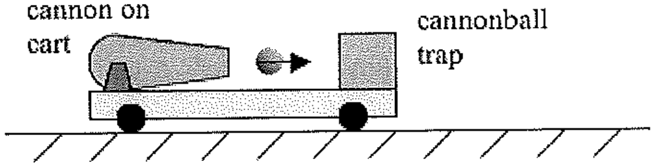
$$Mv = \tfrac{1}{4} M v_1' + \tfrac{3}{4} M v_2'$$

$$v = \tfrac{1}{4} v_1' + \tfrac{3}{4} v_2'$$

$$v_2' = \tfrac{4}{3}(v - \tfrac{1}{4} v_1')$$

$$v_2' = \tfrac{4}{3}(2 - \tfrac{1}{4} 5') = 1 m/s$$

Question:



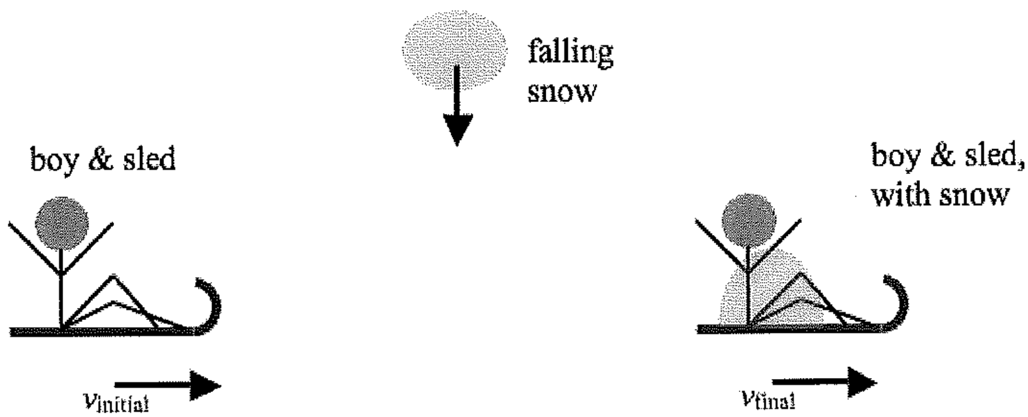
A large cannon is mounted on a cart with frictionless wheels that is initially at rest on a horizontal surface. The cannon fires a large cannonball to the right with a speed $v_{cannonball}$, which is then caught by a trap firmly attached to the cart. What is the final speed v of the cannon-cart-cannonball system?

a. $v > v_{cannonball}$, to the left
b. $v > v_{cannonball}$, to the right
c. 0
d. $v < v_{cannonball}$, to the left
e. $v < v_{cannonball}$, to the right

Answer:
The correct answer is *c*. The overall momentum of the system at the beginning of the problem is 0, and with no external forces applied, this will continue to be the total momentum of the system. During the ball's motion to the right, the cart will have a motion to the left. However, once the cannonball is caught by the trap, they have the same velocity, which has to be zero if linear momentum is to be conserved.

$$m_{cart}v_{cart} + m_{cannonball}v_{cannonball} = m_{cart}'v_{cart}' + m_{cart}v_{cart}'$$
$$(m_{cart} + m_{cannonball})v_{initial} = (m_{cart} + m_{cannonball})v_{final}$$
$$(m_{cart} + m_{cannonball})(0m/s) = (m_{cart} + m_{cannonball})v_{final}$$
$$v_{final} = 0m/s$$

Question:



A boy on a sled is sliding with negligible friction along an icy, horizontal surface. As the sled passes underneath a tree, a large mass of snow falls vertically and lands on the moving sled. Which of the following statements is *false?*

a. The snow collides inelastically with the sled.
b. The sled will slow down when the snow hits it.
c. Conservation of kinetic energy cannot be used to find the final velocity of the sled.
d. Conservation of mechanical energy cannot be used to find the final velocity of the sled.
e. Conservation of linear momentum cannot be used to find the final velocity of the sled.

Answer:

The correct answer is *e*. Conservation of linear momentum *can* be used to solve this problem. The linear momentum of the sled in the horizontal direction remains constant, because no net force is applied in that direction.

$$F_x t = \Delta p_x$$

$$0 = \Delta p_x$$

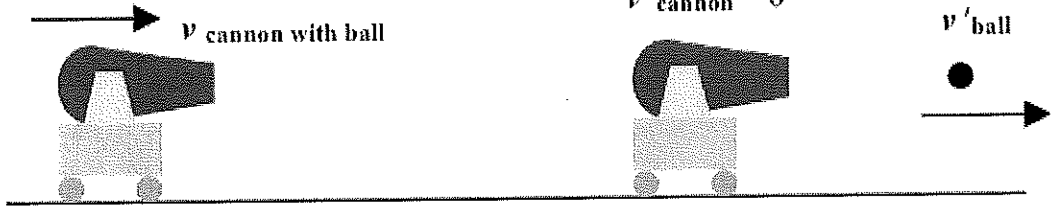
$$m_i v_i = m_f v_f$$

$$m_{sled\,\&\,boy} v_i = (m_{sled\,\&\,boy} + m_{snow}) v_f$$

$$v_f = \frac{m_{sled\,\&\,boy}}{m_{sled\,\&\,boy} + m_{snow}} v_i$$

All the other statements in the problem are true. The snow *does* collide inelastically with the sled, the sled *does* slow down when the snow hits it (as shown in our analysis), and conservation of kinetic and mechanical energies cannot be used to solve for velocity because energy is converted to heat in the collision between the snow and the sled.

Question:



A 20.0 kg cannon attached to a cart with frictionless wheels contains a 5.0 kg cannon ball, and is initially moving to the right at 10 m/s. When the cannon is fired, the cannon ball moves in the positive-x direction while the cannon comes to a halt. What is the velocity of the cannon ball?

a. +50 m/s
b. +100 m/s
c. +200 m/s
d. +500 m/s
e. -100 m/s

Answer:

The correct answer is ***a***. This is a conservation of momentum problem, and the cannon and the ball have the same total momentum before and after the cannon is fired.

Using the conservation of momentum equation:

$$m_{cannon}v_{cannon} + m_{ball}v_{ball} = m_{cannon}v'_{cannon} + m_{ball}v'_{ball}$$

$$(20kg)(10m/s) + (5kg)(10m/s) = (20kg)(0) + (5kg)v'_{ball}$$

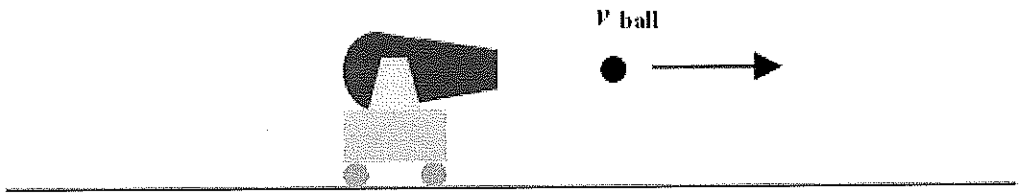
$$250kg \bullet m/s = 0 + (5kg)v'_{ball}$$

Rearrange:

$$v'_{ball} = \frac{250kg \bullet m/s}{5kg} = +50m/s$$

You can think of this kind of problem as a "perfectly inelastic collision in reverse." In a perfectly inelastic collision, two objects with different velocities collide with each other and stick together so that they have one common final velocity. This is the same thing, but backwards: the two objects have a common initial velocity, and then fly apart to have different velocities at the end.

Question:



A 50.0 kg cannon attached to a cart with frictionless wheels contains a 5.0 kg cannon ball, and is initially at rest. When the cannon is fired, the cannon ball moves in the positive-x direction with a velocity of 100 m/s. What is the velocity of the cannon?

a. + 100 m/s
b. −100 m/s
c. +10 m/s
d. −10 m/s
e. The answer can't be found without knowing the impulse on the cannon.

Answer:
The correct answer is ***d***. This is a conservation of momentum problem, where the cannon and the ball have the same total momentum before and after the cannon is fired.

At the beginning of the problem, the cannon and cannonball are at rest, so their total momentum is 0. What does this imply for their total momentum after the cannon is fired? It will *also* be zero, based on the positive velocity of the cannon ball and a negative velocity for the cannon. You can conceptually determing that the cannonball, with 1/10 of the mass of the cannon, will have a velocity that is 10 times greater than the mass of the cannon.

Therefore the velocity of the cannon must be $\frac{100m/s}{10} = 10m/s$ in the negative direction.

We can also use the conservation of momentum formula to determine the same answer:

$$m_{cannon}v_{cannon} + m_{ball}v_{ball} = m_{cannon}v'_{cannon} + m_{ball}v'_{ball}$$

$$(50kg)(0m/s) + (5kg)(0m/s) = (50kg)v'_{cannon} + (5kg)(100m/s)$$

Rearrange:

$$(50kg)v'_{cannon} = -(5kg)(100m/s)$$

$$v'_{cannon} = \frac{-(5kg)(100m/s)}{50kg} = -10m/s$$

This type of problem is commonly called a "recoil" problem, because one of the masses recoils away from the other one.

Question:
A toy car of mass 1.0 kg is rolling east along the floor with a velocity of 2.0 m/s when it collides head-on with a 2.0 kg toy truck that was at rest. After the perfectly inelastic collision, what is the final velocity of the toy car and truck?

a. 4/3 m/s, east
b. 3/4 m/s, east
c. 2/3 m/s, east
d. 3/2 m/s, east
e. 1 m/s, east

Answer:
The correct answer is *c*. Although energy is not conserved in this perfectly inelastic collision, linear momentum *is* conserved. In a perfectly inelastic collision, the two masses become joined, and share a single, final velocity, calculated according to the conservation of linear momentum:

$$p_{car} + p_{truck} = p_{car}' + p_{truck}'$$

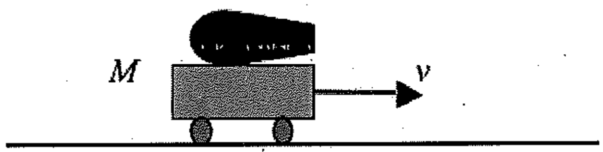
$$m_{car}v_{car} + m_{truck}v_{truck} = m_{car}v_{car}' + m_{truck}v_{truck}'$$

$$m_{car}v_{car} + m_{truck}v_{truck} = (m_{car} + m_{truck})v'$$

$$(1kg)(2m/s) + (2kg)(0m/s) = (1+2)v'$$

$$v' = \frac{2}{3} m/s$$

Question:



A cannon is mounted on a cart, and carrying a cannonball. The total mass of the cart, cannon, and ball is M, and the cart is rolling with no friction at a velocity v in the positive x-direction as shown above. The ball, of mass m, is fired with a velocity of v_{ball} in the positive x-direction. What is the velocity of the cart & cannon after the ball is fired?

a. $\dfrac{Mv - mv_{ball}}{M - m_{ball}}$

b. $\dfrac{Mv - mv_{ball}}{M}$

c. $\dfrac{v - mv_{ball}}{m_{ball}}$

d. $\dfrac{Mv + mv_{ball}}{M - m_{ball}}$

e. $\dfrac{-Mv - mv_{ball}}{M + m_{ball}}$

Answer:

The correct answer is ***a***. This is a conservation of momentum problem, in which the original linear momentum of the cart is equal to the total final momentum of the ball and cart.

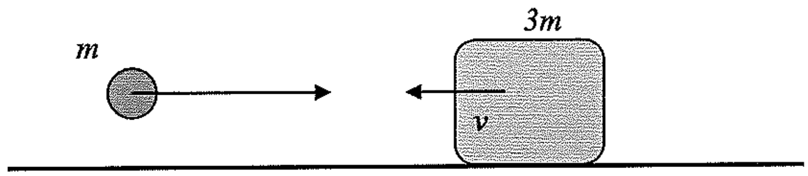
$$\sum p_0 = \sum p_{final}$$

$$p_{cart+ball} = p_{ball} + p_{cart}$$

$$Mv = mv_{ball} + (M - m_{ball})v_{cart}$$

$$v_{cart} = \frac{Mv - mv_{ball}}{M - m_{ball}}$$

Question:



A piece of clay with mass *m* is traveling with an unknown velocity in the positive-*x* direction, when it collides and sticks to a block of mass 3*m*, moving with velocity v = -3 m/s. After the collision, the block and clay are stuck together and traveling with a velocity of 1 m/s in the negative *x*-direction. What was the original velocity of the clay mass?

a. 10 m/s
b. 2 m/s
c. 5 m/s
d. 9 m/s
e. 6 m/s

Answer:
The correct answer is *c*. This is a perfectly inelastic collision, so the initial velocity of the clay can be easily solved for by using conservation of momentum:

$$m_{clay}v_{clay} + m_{block}v_{block} = (m_{clay} + m_{block})v'$$

$$mv_{clay} + 3m(-3m/s) = (m + 3m)(-1m/s)$$

$$v_{clay} - 9 = (4)(-1)$$

$$v_{clay} = 5\,m/s$$

Question:

Two students have masses *M* and *m*, where *M* > *m*, and sit facing each other on identical skateboards that are able to roll with negligible friction. Student *M* momentarily pushes on *m*, causing the two skateboards to roll away from each other. Which of the following statements is true?

a. This force produces an acceleration for *M* that is greater than the acceleration of *m*.
b. The force produces an acceleration for *M* that is equal to the acceleration of *m*.
c. The students will have identical magnitudes of velocity after the push.
d. The students will have identical magnitudes of momentum after the push.
e. The center of mass of the system changes as the students move.

Answer:

The correct answer is ***d***. This is a conservation of momentum problem, in which the total momentum of the system is the same before and after the two students interact. Using conservation of momentum:

$$\sum p_i = \sum p_f$$

$$Mv_{1i} + mv_{2i} = Mv_{1f} + mv_{2f}$$

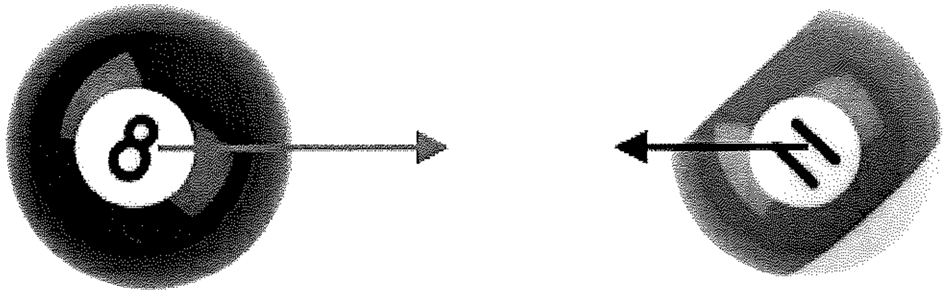
$$0 + 0 = Mv_{1f} + mv_{2f}$$

$$v_{1f} = -\frac{m}{M} v_{2f}$$

The negative sign indicates that the students are moving in opposite directions (similar to the recoil of a fired projectile), and the fraction $\frac{m}{M}$ indicates that the magnitude of v_{1f} is less than v_{2f}. But the two momentums after the push do have to total 0, the same as they were before—therefore, their magnitudes must be the same.

The force of the push from *M* to *m* results in a "force pair" according to Newton's 3rd Law of Motion, with *m* exerting an equal and opposite force back on *M*. Although the forces are equal, the accelerations of the two students are not.

Question:



The 8-ball traveling to the right above strikes the 11-ball, which is of equal mass and moving to the left with a smaller velocity. Which statement below is true?

a. Before the collision, the momentum magnitudes of the two balls are equal.
b. After the collision, the momentum magnitudes of the two balls will be equal.
c. The total amount of momentum before and after the collision is the same.
d. During the collision, the amount of force that the two balls apply to each other will be unequal.
e. The *change* in momentum of the two balls during the collision is different.

Answer:

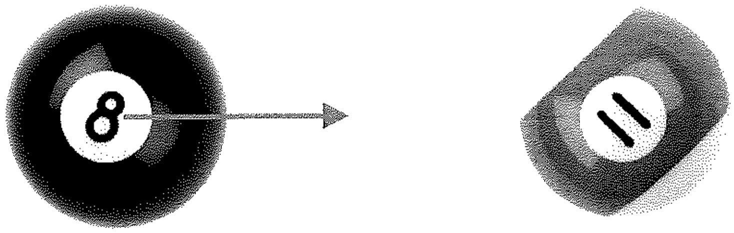
The correct answer is *c*. The two billiard balls have different momentums just before the collision, and as a result of the equal force between them during the collision, will have different momentums after the collision as well. The *change* in momentum of each ball is produced by the impulse they exert on each other, and equal impulses imply equal changes in momentum.

But the *total* momentum of they system will be constant before and after the collision, according to the conservation of momentum:

$$\mathbf{p}_{1i} + \mathbf{p}_{2i} = \mathbf{p}_{1f} + \mathbf{p}_{2f}$$

$$m_1 v_{1i} + m_{21} v_{2i} = m_1 v_{1f} + m_2 v_{2f}$$

Question:



The 8-ball traveling to the right above strikes the 11-ball, which is of equal mass and at rest. If this is an *elastic* collision, which statement below is true?

a. All of the 8-ball's energy and momentum are transferred to the 11-ball.
b. All of the 8-ball's energy and some of its momentum is transferred to the 11-ball.
c. Some of the 8-ball's energy and all of its momentum is transferred to the 11-ball.
d. In this collision, momentum is *not* conserved.
e. In this collision, energy is *not* conserved.

Answer:
The correct answer is *a*. By definition, an *elastic collision* is one in which both kinetic energy and momentum are conserved. There are a number of ways that this can happen, but when a moving mass hits a stationary object of the same mass straight on, the first mass stops (due to the force between the two balls acting on it) and the second mass begins moving (due to that same force).

In your studies, you may have learned that an elastic collision is one in which no energy has been converted ("lost") to heat. But isn't there a small amount of energy lost in the collision of the billiard balls? We certainly hear the "click" as they collide with each other, and that sound represents a small loss of kinetic energy. This is true, so technically speaking, this collision is *not* an elastic collision! Still, the amount of energy lost in this particular example is so small that most physics teachers are comfortable with asking you to consider it as an elastic collision so that you can practice solving those types of problems. In real life, collisions between molecules of matter are a better example of elastic collisions.

Question:
A student kicks a soccer ball straight up into the air, and wants to calculate the Work done on the ball by the foot during the kick based on how high the ball goes. Another student correctly explains that this strategy won't work because:

a. the maximum gravitational potential energy of the ball is less than expected due to air friction
b. some energy from the foot was converted to heat during the collision with the ball
c. the foot and the ball experienced an inelastic collision
d. all three of the above (*a*, *b*, and *c*)
e. none of the above (neither *a*, *b*, nor *c*)

Answer:
The correct answer is ***d***. During the collision between the ball and the foot, energy was converted to heat, so not all of the Work done by the foot on the ball goes into kinetic energy. This is, by definition, an *inelastic collision*.

Also, when the ball travels up through the air, it experiences a force of air friction that impedes its motion. Here again we see energy—the kinetic energy of the ball, in this case—converted to heat, so the ball doesn't travel as high as it might otherwise.