Momentum and Impulse
Concept Tests

Question 1 Consider two carts, of masses *m* and 2*m*, at rest on an air track. If you push first one cart for 3 s and then the other for the same length of time, exerting equal force on each, the momentum of the light cart is

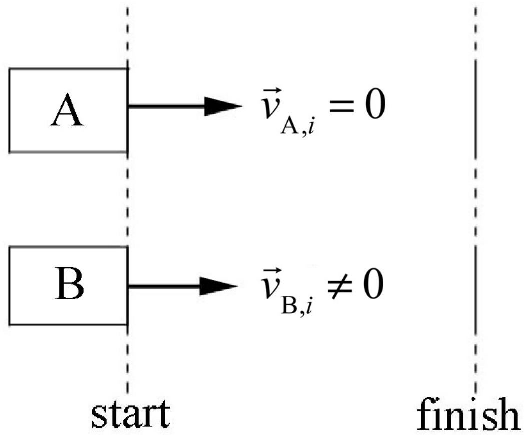
1. four times
2. twice
3. equal to
4. one-half
5. one-quarter

the momentum of the heavy cart.

Answer 3. The change in momentum is equal to the impulse. For a constant force, the impulse is equal to the product of the force with the time interval the force is applied.. Because the forces on the carts are equal, as are the times over which the forces act, the impulses applied to each cart are equal hence the change in momenta are equal. Since both carts start from rest, the final momenta of the two carts are equal.

Question 2 Pushing Identical Carts

Identical constant forces push two identical objects A and B continuously from a starting line to a finish line. If A is initially at rest and B is initially moving to the right,



1. Object A has the larger change in momentum.
2. Object B has the larger change in momentum.
3. Both objects have the same change in momentum
4. Not enough information is given to decide.

Answer 1: Both objects have the same mass, are pushed the same distance, by the same constant force, so they have the same acceleration. Since object B has an initial speed the time interval needed to reach the finish is less than the corresponding time interval for object A which started from rest. Therefore the change in velocity of object B is less than the corresponding change in velocity for object A. Hence object A has a larger change in momentum.

Question 3 Pushing Non-Identical Carts

Consider two carts, of masses *m* and 2*m*, at rest on an air track. If you push first one cart for 3 s and then the other for the same length of time, exerting equal force on each, the kinetic energy of the light cart is

1. larger than

2. equal to

3. smaller than

the kinetic energy of the heavy car.

Answer 1. The kinetic energy of an object can be written as

$$K = \frac{1}{2}mv^2 = \frac{p^2}{2m}$$

Because the impulse is the same for the two carts, the change in momentum is the same. Both start from rest so they both have the same final momentum. Since the mass of the lighter cart is smaller than the mass of the heavier cart, the kinetic energy of the light cart is larger than the kinetic energy of the heavy cart.

Question 4: Same Momentum Different Masses

Suppose a ping-pong ball and a bowling ball are rolling toward you. Both have the same momentum, and you exert the same force to stop each. How do the distances needed to stop them compare?

1. It takes a shorter distance to stop the ping-pong ball.
2. Both take the same distance.
3. It takes a longer distance to stop the ping-pong ball.
4. Not enough information is given to decide.

Answer 3.

Since the ping pong ball and the bowling ball have the same momentum, the kinetic energy of the less massive ping pong ball is greater than the kinetic energy of the more massive bowling ball since $K = p^2 / 2m$. You must do work on an object to change its kinetic energy. If you exert a constant force, then the work done is the product of the force with the displacement of the point of application of the force. Since the work done on an object is equal to t he change in kinetic energy, the ping pong ball has a greater change in kinetic energy in order to bring it to a stop, so the you need a longer distance to stop the ping pong ball.

Alternative Solution: Both the initial momentum and the force acting on the two objects are equal. Therefore the initial velocity and the acceleration of the ping-pong ball isgreater than the bowling ball by the ratio of the bowling ball mass to the ping-pong ball mass.

$$m_p v_{0,p} = m_b v_{0,b} = p_x$$

$$m_p a_p = m_b a_b = F_x$$

Since both the force acting on each object and the change in momentum is the same, the impulse acting on each ball is the same. Therefore, the time interval it takes to stop each object is the same. Since the displacement is equal to

$$\Delta x = \left(v_{x,0} - \frac{a_x \Delta t}{2} \right) \Delta t$$

The ratio

$$\frac{\Delta x_p}{\Delta x_b} = \frac{m_b}{m_p}$$

hence the ping-pong has the greater displacement.

Question 5

A ball is thrown against a wall; the ball bounces off and returns with speed equal to the speed it had before striking the wall. Which of the following statements is true from before to after the collision between the ball and the wall? Explain your answer.

1) The kinetic energy of the ball is the same.
2) The momentum of the ball is the same.
3) Both the kinetic energy and the momentum of the ball are the same.
4) Neither the kinetic energy nor the momentum of the ball are the same.
5) The collision is inelastic.
6) Two of the above.

Solutions:

1) True – speed is given as unchanged.

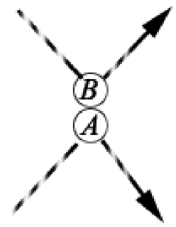
2) Not true – momentum is a vector, and the direction of the ball's direction is reversed, and the momentum cannot be the same after bouncing off the wall. The magnitude of the momentum is the same, but that's not what this question asks.

3,4) Can't be, since 1) is true and 2) is not.

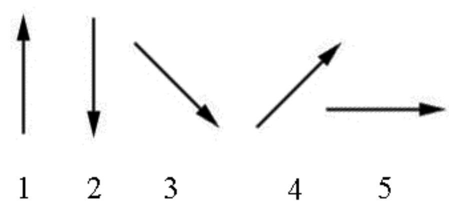
5) Not true - if the speed is the same, the collision is elastic.

6) Not true, since only 1) is true.

Question 6 The figure below depicts the paths of two colliding steel balls, *A* and *B*.



Which of the arrows 1-5 best represents the impulse applied to ball B by ball A during the collision? Explain your answer.



Solution:

1; Ball B has changed its momentum in the upward direction in the figure, and as far as the figure can show, there is no change in its horizontal (rightward) velocity.

Question 7

A force of magnitude F is applied to a dumbbell first as in (a) and then as in (b). In which case does the dumbbell acquire the greater center-of-mass acceleration? Explain your reasoning.

(a) (b)

Solution

It doesn't matter. For practical purposes, it might be hard to maintain a force in a constant direction for case (b), as the dumbbell would tend to rotate (we'll deal with this when we get to rotational motion, of course), but as long as the forces are applied in the same direction, the acceleration of the center of mass will be the same. You might anticipate (or you might have seen in some other physics class) that in case (b) the upper end of the dumbbell, where the force is applied, will initially move twice as fast as the center of mass. Still, the center of mass will accelerate the same in both cases.

Question 8

Skater A of mass 75 kg and skater B of mass 50 kg are initially at rest some distance apart. Each skater holds tightly onto a rope of negligible mass. Skater A pulls on the rope with constant force so that the skaters approach each other and meet. The ice is completely frictionless. Which statements below are true and which are false? Explain your reasoning.

1. Only skater B moves relative to the ice.
2. The magnitude of the acceleration of skater A is less than the magnitude of the acceleration of skater B.
3. Just before they meet, the speed of skater A is less than the speed of B.
4. While the skaters are moving, their momentum vectors have equal magnitudes.

Solution

Before giving the answers, consider that saying that "Skater A only pulls on the rope" is perhaps misleading (not intentionally, of course). The force that skater A exerts on the rope and the force that the rope exerts on skater A are an action-reaction pair, as are the forces that skater B and the rope exert on each other. Thus, to hold onto the rope, skater B must be pulling on the rope as well; as the problem states, skater B "holds tightly" to the rope. If we assume a massless rope, as given in the problem statement, then the magnitude of the net force on each skater is the same.

Thus, statement (1) is false. Statements (2) and (3) are true, and of course are sort of the same statement, in slightly different forms, given that both skaters are initially at rest. Since the mass of the rope is neglected, the magnitude of the net force is the same, as mentioned above, and as there is no net force on the skaters/rope system, the momenta of the skaters must be equal in magnitude (but opposite in direction).