CONSERVATION OF MOMENTUM & COLLISIONS

Conservation of Momentum & Collisions

1. If there is no net external force acting on a system, which of the following is true? (Select all that apply)
   - A The momentum of each object in the system is conserved
   - B The system is isolated
   - C The total momentum in the system is conserved
   - D The total momentum in the system is zero

2. True or false: If a system consists of 3 objects that are all moving, the total momentum of the system can be zero.

3. A system consists of several objects and the components of the total momentum of the system are p_x and p_y. If a net impulse is exerted on the system (by an external force), which of the follow is true?
   - A p_x and p_y will both change
   - B Either p_x or p_y will change but not both
   - C Either p_x or p_y or both will change
   - D p_x and p_y will stay the same

4. There are two objects in an isolated system. At one moment object A is moving in the positive y direction and object B is moving in the negative x direction. Some time later, if object A is moving in the negative x direction, in which direction is object B moving?
   - A The positive x direction
   - B The positive y direction
   - C The negative x direction
   - D The negative y direction

5. Two object collide within an isolated system. Object A has a greater mass than object B. Which of the following is true?
   - A The impulse exerted on object A by object B is equal in magnitude to the impulse exerted on object B by object A
   - B The impulse exerted on object A by object B is greater in magnitude than the impulse exerted on object B by object A
   - C The impulse exerted on object A by object B is smaller in magnitude than the impulse exerted on object B by object A
   - D There is no impulse exerted on either object

6. Momentum is conserved during which of the following events? (Select all that apply)
   - A Two objects collide and stick together
   - B Two objects collide then move away from each other and kinetic energy is conserved
   - C A compressed spring is released between two objects, pushing them in opposite directions (the system is defined as the two objects and the spring)
   - D Two objects collide then move away from each other and kinetic energy is not conserved

7. A clay ball is thrown at a block which is hanging from the ceiling by a string. The clay ball sticks to the block and the two objects swing upwards. Which of the following is conserved during the collision? (Select all that apply)
   - A The total momentum of the clay ball and the block
   - B The total velocities of the clay ball and the block
   - C The total kinetic energy of the clay ball and the block
   - D None of the above

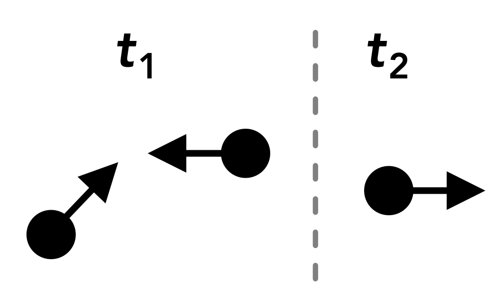
8. Block A and block B are sliding on a frictionless track towards each other when they collide. The collision is perfectly elastic. Which of the following equations correctly relates the masses, initial velocities and final velocities of the blocks before and after the collision? (Select all that apply)
   - A $\frac{1}{2}m_A v_{Ai}^2 + \frac{1}{2}m_B v_{Bi}^2 = \frac{1}{2}m_A v_{Af}^2 + \frac{1}{2}m_B v_{Bf}^2$
   - B $v_{Ai} + v_{Af} = v_{Bi} + v_{Bf}$
   - C $m_A v_{Ai} + m_B v_{Bi} = (m_A + m_B) v_f$
   - D $m_A v_{Ai} + m_B v_{Bi} = m_A v_{Af} + m_B v_{Bf}$

9. The total kinetic energy of a system is conserved during which of the following events? (Select all that apply)
   - A An explosion
   - B A perfectly elastic collision
   - C An inelastic collision (a partially elastic collision)
   - D A perfectly inelastic collision

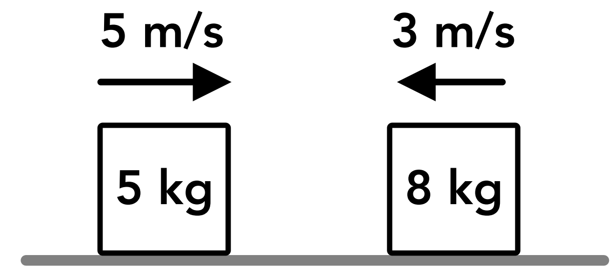
10. A system consists of three rotating objects. If there is no net external torque exerted on the system, which of the following is true? (Select all that apply)
    - A The total angular momentum of the system is zero
    - B The total rotational kinetic energy of the system is conserved
    - C The angular momentum of each object is conserved
    - D The total angular momentum of the system is conserved

11. A figure skater is spinning in place with their arms straight out away from their body. What will happen if they pull their arms in close to their body?
    - A They will spin faster
    - B They will spin slower
    - C Their angular speed will stay the same
    - D A change to their angular speed cannot be determined

12. Two objects are moving in the directions shown on the right at a time of t_1. At a later time t_2 one of the objects is moving in the direction shown. Which of the following shows the possible direction that the other object is moving at t_2? (The size of the objects and velocity vectors are not drawn to scale).

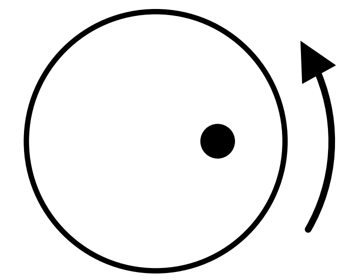


13. Two blocks are sliding on a frictionless surface as shown on the right. If they collide and stick together, which direction do they move after the collision?



- A Right
- B Left
- C They're not moving after the collision
- D Cannot be determined

14. A top-down view of a person standing on a spinning merry-go-round is shown on the right. The platform is spinning freely on a center axle with no external force turning it. If the person wants slow down the platform, which direction should they walk?



- A Towards the center of the platform
- B Towards the outer edge of the platform
- C Neither of the above will change the speed of the platform

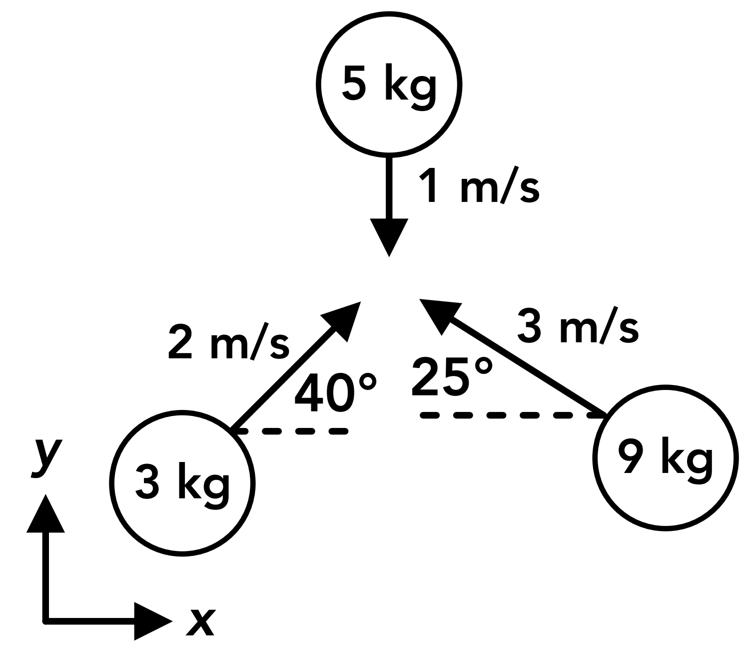
15. A 2 kg block and a 6 kg block are sliding directly towards each other on ice with negligible friction. The 2 kg block is moving to the right at 1 m/s and the 6 kg block is moving to the left at 3 m/s. After the collision, the 2 kg block is moving to the left at 5 m/s. What is the speed and direction of the 6 kg block?

16. A 3 kg wood block is suspended from the ceiling using a string with negligible mass. A 30 g bullet is fired at the block at 300 m/s. The bullet enters one side and stays in the block. How fast is the block moving immediately after the bullet gets stuck?

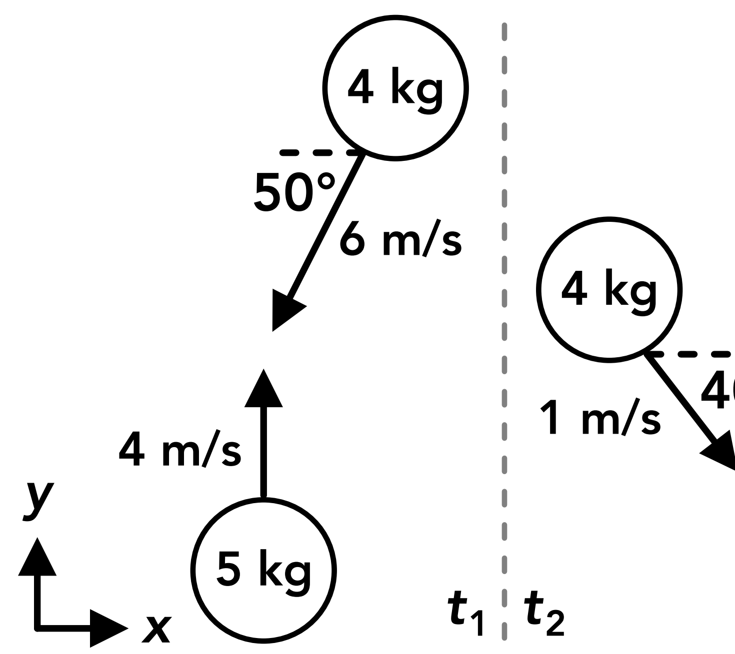
17. Two astronauts are playing catch while floating in the International Space Station (ISS). Both astronauts start out stationary (not moving) relative to the ISS. Astronaut A, who has a mass of 75 kg, throws the 2 kg ball at a speed of 4 m/s (relative to the ISS) towards astronaut B, who has a mass of 85 kg, who catches it. After the throw and catch, what is the speed of each astronaut?

18. Two cars are sliding towards each other of a frictionless track. Car A has a mass of 3 kg and a speed of 0.5 m/s. Car B has a mass of 4 kg and a speed of 0.8 m/s. If the cars hit each other and the collision is perfectly elastic, what is the speed of car B after the collision?

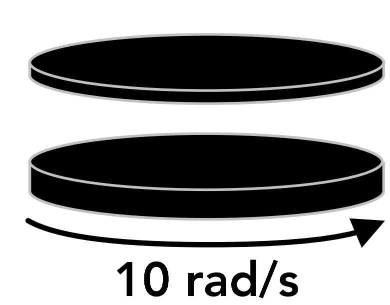
19. What are the x and y components of the total momentum of the 3-object system shown on the right?



20. The velocities of two objects at time t_1 are shown on the right. The objects collide and the velocity of one of the objects is shown after the collision at time t_2. What is the speed of the other object after the collision?



21. A solid disk with a mass of 5 kg and a radius of 40 cm is spinning at 10 rad/s. Another disk with a mass of 2 kg and the same radius, which is not spinning, is dropped onto the spinning disk from above and the two disks stick together. What is the new angular speed of the two disks?



Answers

1. B, C
2. True
3. C
4. B
5. A
6. A, B, C, D
7. A
8. A, B, D
9. B
10. D
11. A
12. C
13. A
14. B
15. 1 m/s, left
16. 2.97 m/s
17. A = 0.11 m/s, B = 0.09 m/s
18. 0.31 m/s
19. $\sum \boldsymbol{p}_x$= -19.9 kg·m/s, $\sum \boldsymbol{p}_y$= 10.3 kg·m/s
20. 3.8 m/s
21. 7.14 rad/s

Answers - Conservation of Momentum & Collisions

1. **Answer: B, C**
   If there is no net external force acting on the system then the system is isolated and the total momentum in the system is conserved (not the momentum of each object in the system).

2. **Answer: True**
   An object's momentum is a vector which has a magnitude and a direction (the same direction as the object's velocity). It's possible for the total momentum of the three objects to be zero. For example, if two objects are moving in one direction and the third object is moving in the opposite direction, and the masses and velocities are such that the total momentum of the two objects is equal in magnitude to the momentum of the third object.

3. **Answer: C**
   A net impulse exerted on a system will change the total amount of momentum in the system (momentum is not conserved). If the impulse (and the external force) is in the $\boldsymbol{x}$ or $\boldsymbol{y}$ direction, then only $\boldsymbol{p}_x$ or $\boldsymbol{p}_y$ will change. If the impulse has $\boldsymbol{x}$ and $\boldsymbol{y}$ components then $\boldsymbol{p}_x$ and $\boldsymbol{p}_y$ will both change.

4. **Answer: B**
   The total momentum of the system is conserved in the $\boldsymbol{x}$ and $\boldsymbol{y}$ directions. At the initial time the system has a total momentum with a positive $\boldsymbol{y}$ component and a negative $\boldsymbol{x}$ component, so it must have the same components in the same directions at any other time.

5. **Answer: A**
   A system is isolated and the total momentum is conserved if there is no net external impulse exerted on the system by an external force, but objects exert impulses on each other when they collide within the system. The The impulse exerted on object A by object B is equal in magnitude to the impulse exerted on object B by object A, but the impulses are in opposite directions, so the total impulse and the total change in momentum is zero.

6. **Answer: A, B, C, D**
   Momentum is conserved during each of these events (assuming there are no net external forces acting on the system). Option A is a perfectly inelastic collision, option B is a perfectly elastic collision, option C is an explosion (the spring force is an internal force) and option D is an inelastic collision (partially elastic).

7. **Answer: A**
   The objects stick together so this is a perfectly inelastic collision. The total momentum is conserved but the total kinetic energy is not conserved.

8. **Answer: A, B, D**
   The system of the two blocks is isolated so momentum is conserved (option D). The collision is perfectly elastic so kinetic energy is also conserved (option A). By combining those two equations we get the equation in option B which can be used in combination with the conservation of momentum equation as a shortcut for some perfectly elastic collision problems. Option C would be used for a perfectly inelastic collision.

9. **Answer: B**
   Kinetic energy is only conserved during perfectly elastic collisions.

10. **Answer: D**
    If there is no net external torque acting on a system then the total angular momentum of the system is conserved.

11. **Answer: A**
    The angular momentum of the skater is conserved. By bringing their arms in closer to their body they are decreasing their rotational inertia (their mass is closer to the axis of rotation), so their angular speed must increase to maintain the same angular momentum.
    $L = I\omega$

12. **Answer: C**
    At time t_1 the total momentum of the two objects has an upwards vertical component and an unknown horizontal component (it could be right, left or zero). If we assume momentum is conserved between the two times, the total momentum at time t_2 must also have an upwards vertical component. The first object shown does not have an upwards component so the second object must have an upwards component.

13. **Answer: A**
    The total momentum of the two blocks is conserved during the collision, which is a perfectly inelastic collision. The total momentum is to the right before the collision so they move together to the right after the collision. If we say right is the positive direction:
    $\sum p_{xi} = \sum p_{xf}$ $\quad m_1 v_{1xi} + m_2 v_{2xi} = (m_1 + m_2) v_f$ $\quad (5 \text{ kg})(5 \text{ m/s}) + (8 \text{ kg})(-3 \text{ m/s}) = (5 \text{ kg} + 8 \text{ kg}) v_f$
    $v_f = 0.08$ m/s (positive, to the right)

14. **Answer: B**
    The total angular momentum of the person and platform system is conserved. By walking towards the outer edge of the platform, away from the center, they are increasing the rotational inertia of the system so the angular speed of the system must decrease.
    $L = I\omega$

15. **Answer: 1 m/s, left**
    The total momentum of the two blocks is conserved. If we say right is positive:
    $\sum p_{xi} = \sum p_{xf}$ $\quad (2 \text{ kg})(1 \text{ m/s}) + (6 \text{ kg})(-3 \text{ m/s}) = (2 \text{ kg})(-5 \text{ m/s}) + (6 \text{ kg}) v_f$ $\quad v_f = -1$ m/s (1 m/s, left)

16. **Answer: 2.97 m/s**
    This is a perfectly inelastic collision and the bullet and block move together with the same velocity afterwards.
    $\sum p_{xi} = \sum p_{xf}$ $\quad (0.03 \text{ kg})(300 \text{ m/s}) + (3 \text{ kg})(0 \text{ m/s}) = (0.03 \text{ kg} + 3 \text{ kg}) v_f$ $\quad v_f = 2.97$ m/s

17. **Answer: A = 0.11 m/s, B = 0.09 m/s**
    This is a series of two events, an explosion (the throw) and a perfectly inelastic collision (the catch). Momentum is conserved during each event. During the throw, if we say the ball moves in the positive direction:
    $\sum p_{xi} = \sum p_{xf}$ $\quad (75 \text{ kg} + 2 \text{ kg})(0 \text{ m/s}) = (75 \text{ kg}) v_{Af} + (2 \text{ kg})(4 \text{ m/s})$ $\quad v_{Af} = -0.11$ m/s
    During the catch:
    $\sum p_{xi} = \sum p_{xf}$ $\quad (80 \text{ kg})(0 \text{ m/s}) + (2 \text{ kg})(4 \text{ m/s}) = (85 \text{ kg} + 2 \text{ kg}) v_f$ $\quad v_{Bf} = 0.09$ m/s

18. **Answer: 0.31 m/s**
The collision is perfectly elastic so momentum and kinetic energy are conserved. We can use the conservation of momentum equation and the conservation of kinetic energy equation and solve for the two unknown final velocities. Or we can use the conservation of momentum equation and the "shortcut" equation which is derived by combining the conservation of momentum and conservation of kinetic energy equations. If we say car A is moving in the positive direction before the collision, we can start with the conservation of momentum:
$\sum p_{xi} = \sum p_{xf}$ $\quad (3\text{ kg})(0.5\text{ m/s}) + (4\text{ kg})(-0.8\text{ m/s}) = (3\text{ kg})v_{Axf} + (4\text{ kg})v_{Bxf}$
Then we can use the "shortcut" equation to get a second equation with the two unknown final velocities:
$v_{Ai} + v_{Af} = v_{Bi} + v_{Bf}$ $\quad (0.5\text{ m/s}) + v_{Axf} = (-0.8\text{ m/s}) + v_{Bxf}$
If we solve the system of two equations for the two unknown final velocities:
$v_{Axf} = -0.99\text{ m/s}$ $\quad v_{Bxf} = 0.31\text{ m/s}$

19. **Answer: $\sum p_x = -19.9$ kg·m/s, $\sum p_y = 10.3$ kg·m/s**
$\sum p_x = (3\text{ kg})(2\text{ m/s})\cos(40°) - (9\text{ kg})(3\text{ m/s})\cos(25°) = -19.9\text{ kg·m/s}$
$\sum p_y = (3\text{ kg})(2\text{ m/s})\sin(40°) + (9\text{ kg})(3\text{ m/s})\sin(25°) - (5\text{ kg})(1\text{ m/s}) = 10.3\text{ kg·m/s}$

20. **Answer: 3.8 m/s**
The total momentum is conserved in the ***x*** and ***y*** directions. We can find the components of the 5 kg object's momentum after the collision and use those to find the magnitude of the velocity (the speed).
$\sum p_{xi} = \sum p_{xf}$ $\quad -(4\text{ kg})(6\text{ m/s})\cos(50°) = (5\text{ kg})v_{xf} + (4\text{ kg})(1\text{ m/s})\cos(40°)$ $\quad v_{xf} = -3.70\text{ m/s}$
$\sum p_{yi} = \sum p_{yf}$ $\quad (5\text{ kg})(4\text{ m/s}) - (4\text{ kg})(6\text{ m/s})\sin(50°) = (5\text{ kg})v_{yf} - (4\text{ kg})(1\text{ m/s})\sin(40°)$ $\quad v_{yf} = 0.84\text{ m/s}$
$v_f = \sqrt{(-3.70\text{ m/s})^2 + (0.84\text{ m/s})^2} = 3.8\text{ m/s}$

21. **Answer: 7.14 rad/s**
This is a perfectly inelastic collision and the total angular momentum of the two disks is conserved.
Top disk: $I = \frac{1}{2}mR^2 = \frac{1}{2}(2\text{ kg})(0.4\text{ m})^2 = 0.16\text{ kg·m}^2$
Bottom disk: $I = \frac{1}{2}mR^2 = \frac{1}{2}(5\text{ kg})(0.4\text{ m})^2 = 0.4\text{ kg·m}^2$
$\sum L_i = \sum L_f$ $\quad I_1\omega_{1i} + I_2\omega_{2i} = (I_1 + I_2)\omega_f$ $\quad (0.16\text{ kg·m}^2)(0\text{ rad/s}) + (0.4\text{ kg·m}^2)(10\text{ rad/s}) = (0.56\text{ kg·m}^2)\omega_f$
$\omega_f = 7.14\text{ rad/s}$