

Part A: Concepts

Answer in complete sentences.

1. Liam fires a paintball gun while standing still on a skateboard. Explain, using momentum, why Liam rolls backward. Why does the paintball move much faster than Liam?

Liam, the gun, and the paintball start at rest, so the total momentum is **zero** before and must be zero after. The paintball gets momentum forward, so Liam must get an equal amount of momentum **backward**.

The momenta are equal in size, $m_{\text{ball}} v_{\text{ball}} = m_{\text{Liam}} v_{\text{Liam}}$. The paintball has a tiny mass, so it needs a much larger velocity to have the same size momentum.

2. Maya says a rocket cannot work in space because there is no air to push against. Is she right? Explain what the rocket really pushes on.

No. A rocket pushes on its own exhaust gas, not on the air. It shoves gas out the back with momentum backward, and the gas pushes the rocket forward with an equal amount of momentum. This works in the vacuum of space.

Part B: Calculations

Show knowns, equation, substitution, and answer with units. Right is positive.

3. A 4.0 kg rifle at rest fires a 0.010 kg bullet to the right at 400 m/s. What is the recoil velocity of the rifle?

Knowns: $m_r = 4.0 \text{ kg}$, $m_b = 0.010 \text{ kg}$, $v_b' = +400 \text{ m/s}$, everything starts at rest

Equation: $0 = m_r v_r' + m_b v_b'$, so $v_r' = -m_b v_b' / m_r$

Bullet's momentum: $(0.010 \text{ kg})(+400 \text{ m/s}) = +4.0 \text{ kg}\cdot\text{m/s}$

Substitute: $v_r' = -(4.0 \text{ kg}\cdot\text{m/s}) / (4.0 \text{ kg})$

Answer: $v_r' = -1.0 \text{ m/s}$, or **1.0 m/s to the left**

4. A 78.0 kg hockey player and a 52.0 kg figure skater stand at rest on the ice and push off each other. The hockey player moves right at 1.20 m/s. What is the velocity of the figure skater?

Knowns: $m_1 = 78.0 \text{ kg}$, $v_1' = +1.20 \text{ m/s}$, $m_2 = 52.0 \text{ kg}$, both start at rest

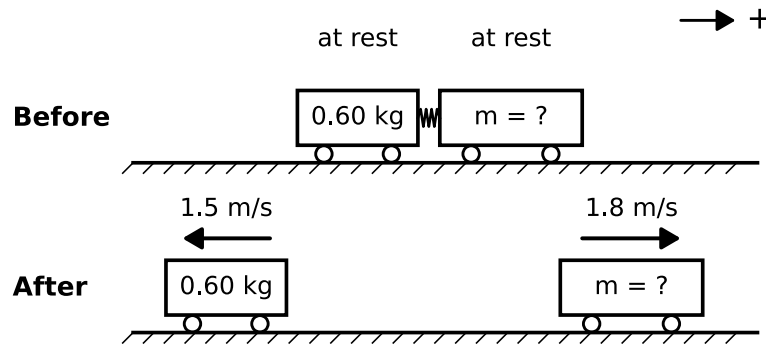
Equation: $0 = m_1 v_1' + m_2 v_2'$, so $v_2' = -m_1 v_1' / m_2$

Hockey player's momentum: $(78.0 \text{ kg})(+1.20 \text{ m/s}) = +93.6 \text{ kg}\cdot\text{m/s}$

Substitute: $v_2' = -(93.6 \text{ kg}\cdot\text{m/s}) / (52.0 \text{ kg})$

Answer: $v_2' = -1.80 \text{ m/s}$, or **1.80 m/s to the left**. The lighter skater moves faster.

5. A compressed spring between two carts is released, and the carts fly apart from rest, as shown. Find the mass of the second cart.



Knowns: $m_1 = 0.60 \text{ kg}$, $v_1' = -1.5 \text{ m/s}$, $v_2' = +1.8 \text{ m/s}$, both start at rest

Equation: $0 = m_1 v_1' + m_2 v_2'$, so $m_2 = -m_1 v_1' / v_2'$

First cart's momentum: $(0.60 \text{ kg})(-1.5 \text{ m/s}) = -0.90 \text{ kg}\cdot\text{m/s}$

Substitute: $m_2 = -(-0.90 \text{ kg}\cdot\text{m/s}) / (+1.8 \text{ m/s}) = 0.90 / 1.8$

Answer: $m_2 = 0.50 \text{ kg}$

6. Sofia (55.0 kg) sits at rest on a 5.0 kg sled on smooth ice. She throws a 3.0 kg ball to the right at 6.0 m/s.

- What is the velocity of Sofia and the sled after the throw?
- If she threw the ball twice as fast, what would happen to her recoil velocity? Explain without redoing the whole problem.

a. System: Sofia + sled + ball, all at rest. Sofia and sled move together: $m_1 = 55.0 \text{ kg} + 5.0 \text{ kg} = 60.0 \text{ kg}$

Equation: $0 = m_1 v_1' + m_2 v_2'$, so $v_1' = -m_2 v_2' / m_1$

Ball's momentum: $(3.0 \text{ kg})(+6.0 \text{ m/s}) = +18 \text{ kg}\cdot\text{m/s}$

Substitute: $v_1' = -(18 \text{ kg}\cdot\text{m/s}) / (60.0 \text{ kg})$

Answer: $v_1' = -0.30 \text{ m/s}$, or **0.30 m/s to the left**

b. Her recoil velocity would **double** to 0.60 m/s to the left. The ball's momentum doubles, so Sofia and the sled need twice as much momentum in the opposite direction, and their mass has not changed.