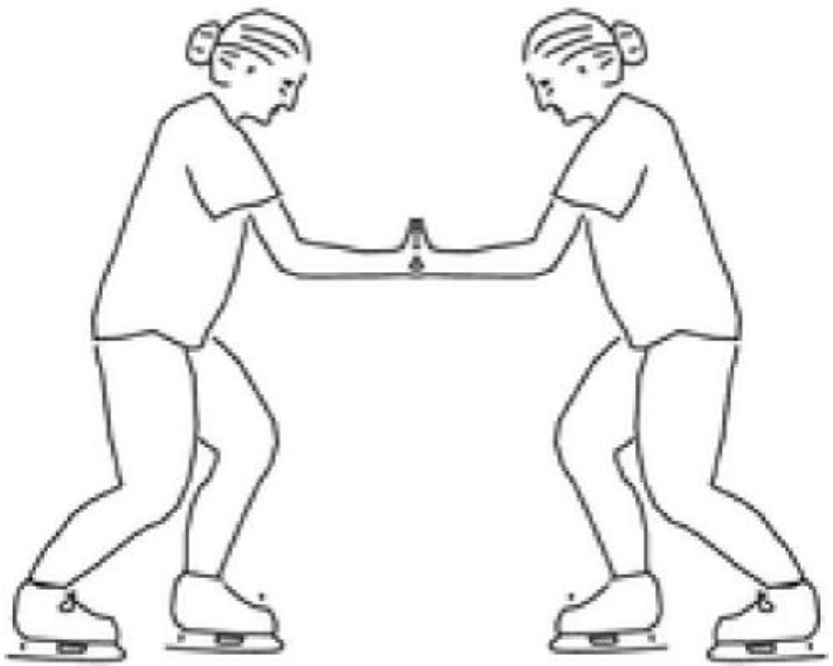
Introduction to Momentum

Level 3 Physics

January 2013

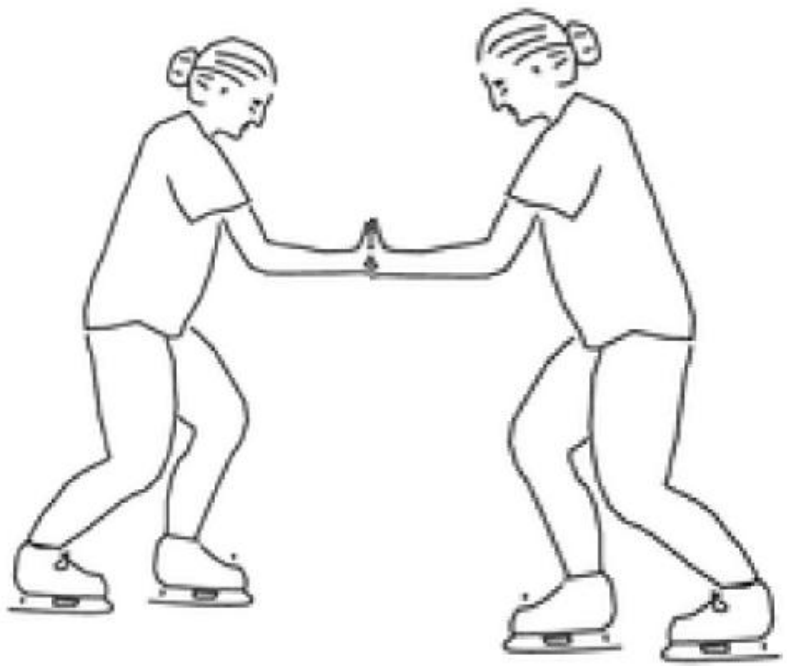
Ice Skating

What happens when two ice skaters push off of each other?



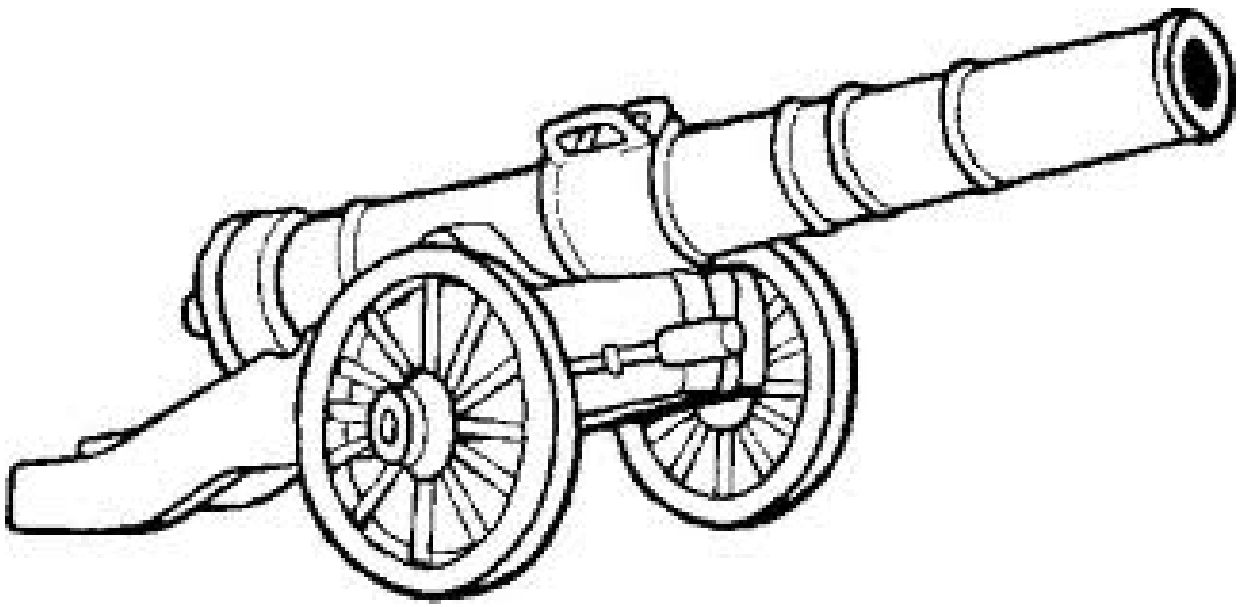
Ice Skating

What is different if one of the ice skaters is larger than the other?



Cannon

What happens to the cannon when it is fired?



Fireworks

Where do the pieces of firework go when it explodes?

Law

These phenomena are explained with a law of physics called the **Conservation of Momentum**.

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Questions to answer:

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Questions to answer:

- What does conservation mean?
- What does momentum mean?
- What is the formula for momentum?
- Under what conditions is the Conservation of Momentum law true?

Conservation

Conservation of Momentum: Version 1

$$momentum_{initial} = momentum_{final}$$

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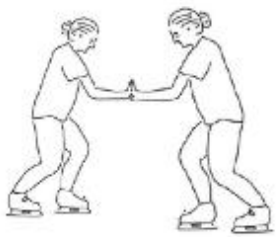
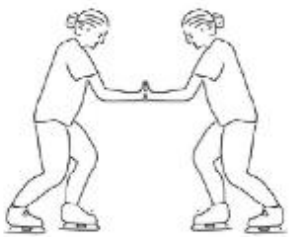
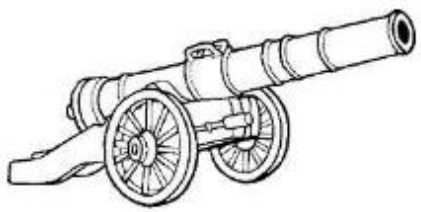
Question: Momentum of what? The **system**.

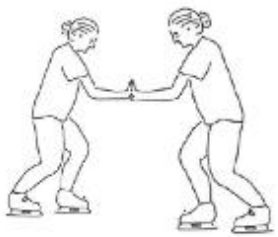
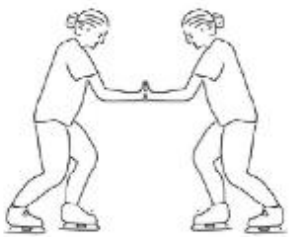
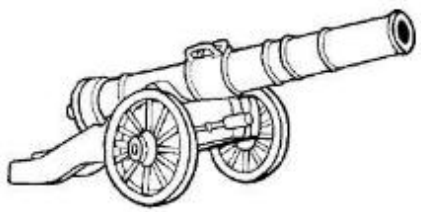
Recall that $F = ma$ required finding the *net* force. Similarly, it is *net* momentum that is conserved.

Components of Momentum


What quantities should be included in the formula for momentum?

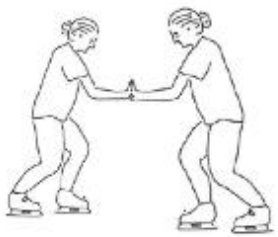
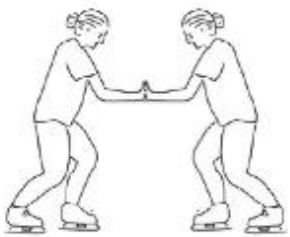
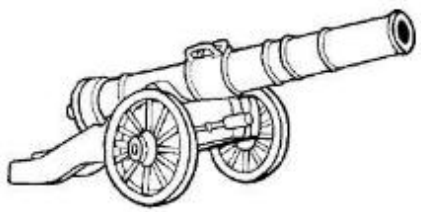
Components of Momentum


What quantities should be included in the formula for momentum?

- Force?

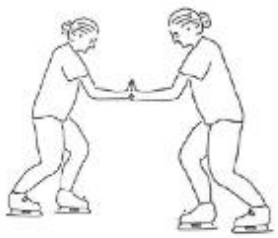
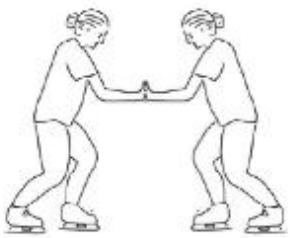
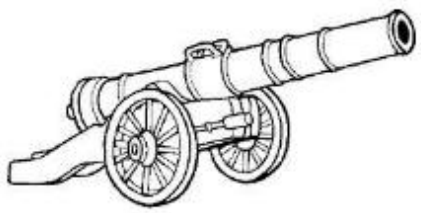
Components of Momentum


What quantities should be included in the formula for momentum?

- Force?
- Position?

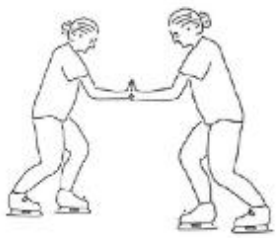
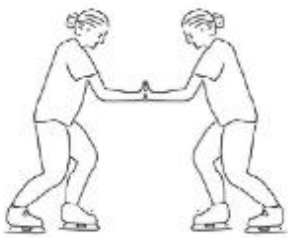
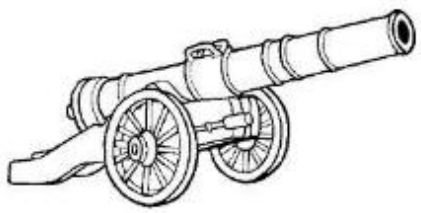
Components of Momentum


What quantities should be included in the formula for momentum?

- Force?
- Position?
- Velocity?

Components of Momentum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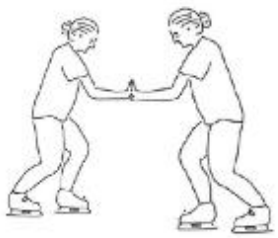
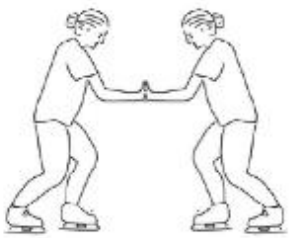
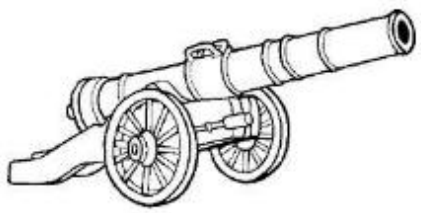
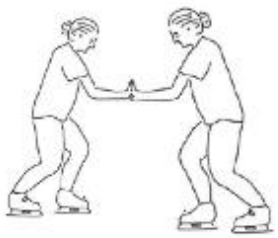
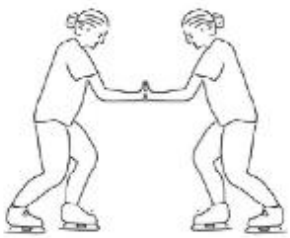
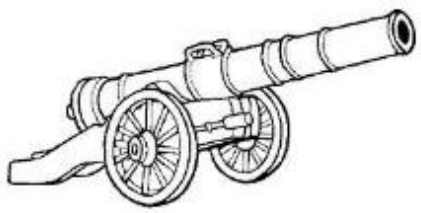





What quantities should be included in the formula for momentum?

- Force?
- Position?
- Velocity?
- Acceleration?
- Mass?

Components of Momentum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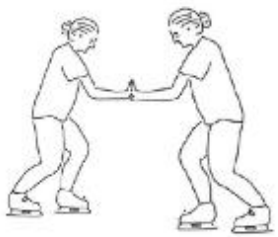
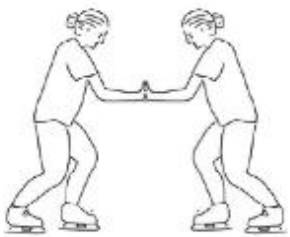
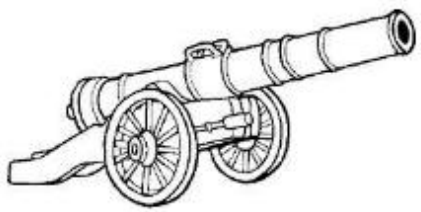


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- Other suggestions?

Mass and Velocity

The formula for momentum should include mass and velocity. But how are they related?

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Directly Proportional

Variables a and b are directly proportional if $a = k * b$ where k is a constant.

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Directly Proportional

Variables a and b are directly proportional if $a = k * b$ where k is a constant.

Inversely Proportional

Variables a and b are inversely proportional if $a * b = k$ where k is a constant.

Formula for Momentum

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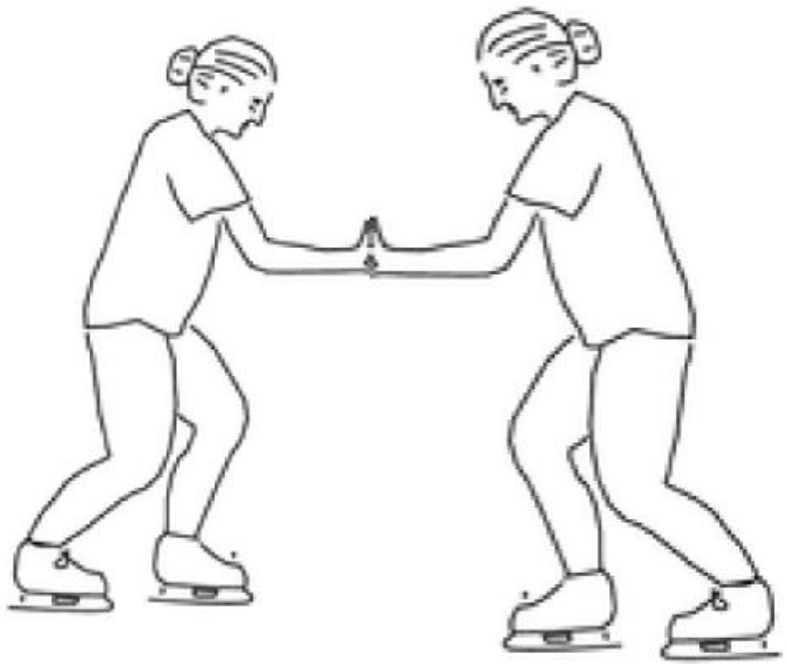
Conservation of Momentum: Version 2

$$\sum p_i = \sum p_f$$
$$\sum m * v_i = \sum m * v_f$$

Testing our Law

To see if our version of the law of Conservation of Momentum is valid, consider the situation of two ice skaters initially at rest who push off of each other. Skater A is on the left and Skater B is on the right.



Testing our Law

Consider these values for the masses and velocities:

Skater A: $m = 40kg, v_i = 0\frac{m}{s}, v_f = -0.5\frac{m}{s}$

Skater B: $m = 50kg, v_i = 0\frac{m}{s}, v_f = 0.4\frac{m}{s}$

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Are the values reasonable? Yes.

Do they satisfy our law? Yes.

$$\begin{aligned}\sum p_i &= m_A * v_{Ai} + m_B * v_{Bi} \\ &= 0\frac{kg*m}{s} \\ \sum p_f &= m_A * v_{Af} + m_B * v_{Bf} \\ &= 40 * (-0.5) + 50 * 0.4 \\ &= 0\frac{kg*m}{s}\end{aligned}$$

Discovering an Issue

Now consider just Skater B, immediately after pushing off from Skater A. We have as before, $m = 50kg$, and now, $v_i = 0.4\frac{m}{s}$.

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Eventually what happens to the skater? $v_f = 0\frac{m}{s}$.

Does this satisfy our law? No.

$$\begin{aligned}\sum p_i &= m * v_i \\ &= 50 * 0.4 \\ &= 20\frac{kg*m}{s} \\ \sum p_f &= m * v_f \\ &= 0\frac{kg*m}{s}\end{aligned}$$

Resolving the Issue

What is wrong?

- Can we ignore Skater A?
- Is there a problem with defining Skater B as the system?
- Are there any other influences on the system?
- Other suggestions?

Resolving the Issue

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- Can we ignore Skater A?
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Conclusion: The net force on the system must be zero.

Final Definitions

Momentum

$$p = m * v$$

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Conservation of Momentum

The net momentum of a system remains constant when there is no net force on the system.

Pigeons and Bees

If a pigeon and a bee are both flying at a speed of $5\frac{m}{s}$, how do their momentums compare?

1. The pigeon has greater momentum
2. The bee has greater momentum
3. The pigeon and bee have the same momentum

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Cows and Ants

A cow has a mass of $600kg$ and is standing still, eating grass. An ant on the ground hass a mass of $0.003g$ and is traveling at a rate of $1\frac{cm}{s}$. How do their momentums compare?

1. The cow has greater momentum
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3. The cow and ant have the same momentum

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Jumping

If I jump straight up, what happens to the Earth as soon as I leave the ground?

1. It doesn't move
2. It moves down
3. It moves up

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2. **It moves down**
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(The mass of the Earth is $5.97x10^{24}$ so the magnitude of the velocity is very small.)

Momentum

Momentum has which of the following?

1. Magnitude
2. Direction
3. Magnitude and direction

Momentum

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2. Direction
3. **Magnitude and direction**

(Momentum is a vector since it is the product of mass (a scalar) and velocity (a vector). Scalars have just magnitude while vectors have both magnitude and direction.)