# Physics 221, February 15

Key Concepts:

- Definition of momentum and impulse
- Conservation of momentum
- The center of mass
- Rockets


Please do not use social media during class.

# Linear momentum

Momentum: $\mathbf{p} = m\mathbf{v}$ (vector)

Rate of change: $\Delta\mathbf{p} / \Delta t = m\Delta\mathbf{v}/\Delta t = m\mathbf{a} = \mathbf{F}$ (vector)

$F_x = \Delta p_x/\Delta t$, $F_y = \Delta p_y/\Delta t$

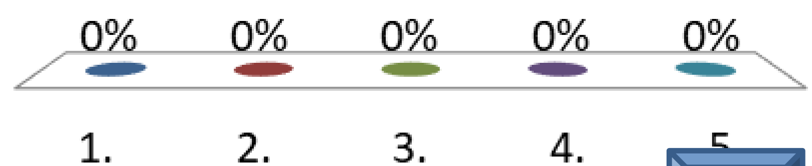
Impulse: $\mathbf{I} = \Delta\mathbf{p} = \mathbf{p}_f - \mathbf{p}_i = \mathbf{F}\Delta t$ (vector)

Kinetic energy: $E_{kin} = ½mv^2 = p^2/(2m)$ (scalar)

$p = (2m*E_{kin})^{1/2}$ (magnitude)

When the kinetic energy of a moving object increases by a factor of 4, the magnitude of its momentum

1. increases by a factor of $\sqrt{2}$.
2. doubles.
3. increases by a factor of 4.
4. decreases by a factor of 16.
5. can increase or decrease depending on factors not stated.

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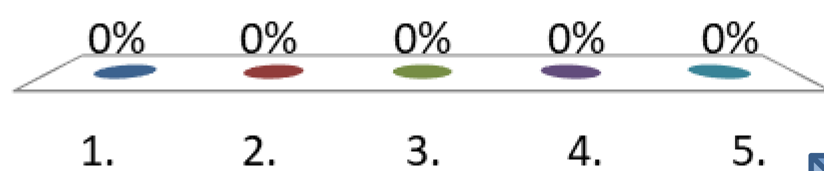
A ball initially at rest is hit by a club. It is in contact with a club for $6.0*10^{-3}$ seconds. Just after the club loses contact with the ball, the ball's velocity is 2.0 m/s. If the ball's mass is 50 g, what is the magnitude of the impulse the club gives to the ball?

1. 100 kg m/s
2. $1.1*10^{-1}$ kg m/s
3. 0.1 kg m/s
4. $1.2*10^{-2}$ kg m/s
5. $3.0*10^{-4}$ kg m/s

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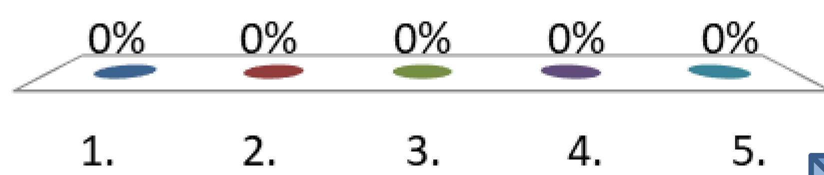
A ball initially at rest is hit by a club. It is in contact with a club for $6.0*10^{-3}$ seconds. Just after the club loses contact with the ball, the ball's velocity is 2.0 m/s. If the ball's mass is 50 g, what was the magnitude of the average net force acting on the ball while in contact with the club?

1. 100 N
2. $1.2*10^{-2}$ N
3. 0.1 N
4. $6*10^{-4}$ N
5. 16.7 N

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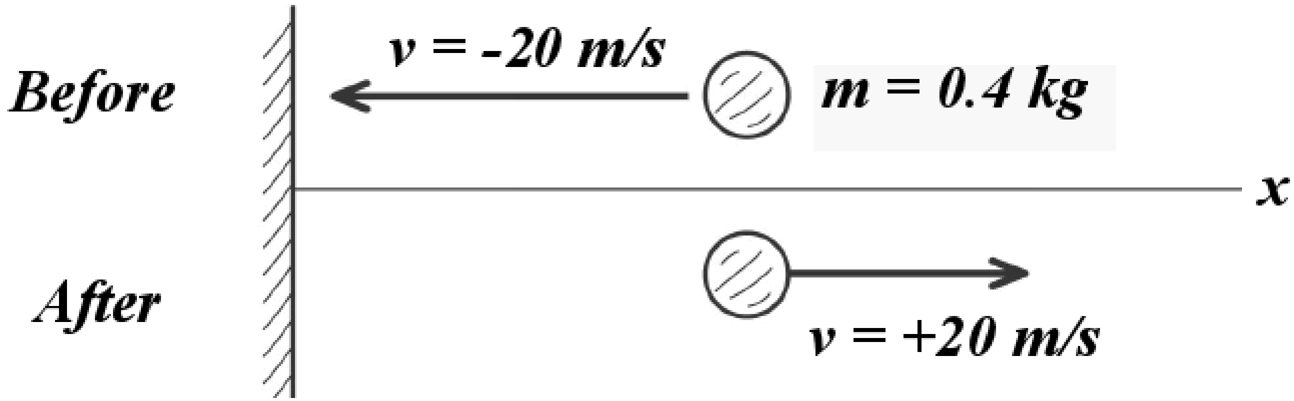
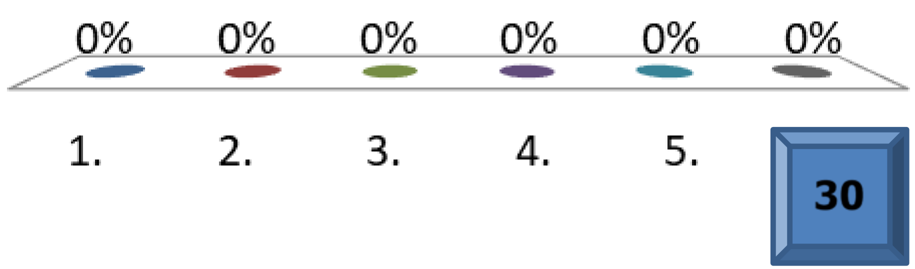
A ball (mass 0.40 kg) is initially moving to the left at 20 m/s. After hitting the wall, the ball is moving to the right at 20 m/s. What is the impulse of the ball receives during its collision with the wall?

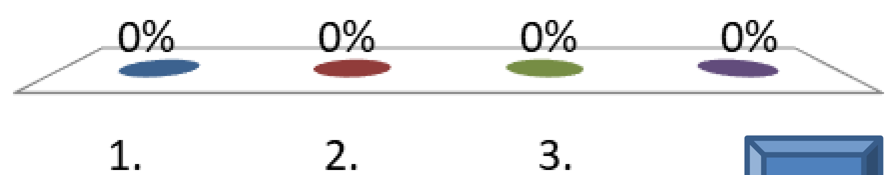



1. 4 kg m/s to the right
2. 4 kg m/s to the left
3. 16 kg m/s to the right
4. 16 kg m/s to the left
5. 4 kg m/s to the right
6. 4 kg m/s to the right



You have heard the tried and true phrase “it is like running in to a brick wall”. Now it is time to dig a little deeper and modify the phrase.
Assume you are in a car driving and come in contact with this proverbial brick wall. Your car can do three things after the strike: it can go through, come to stop or bounce back. Select the option which will be the most dangerous to you assuming similar collision times.

1. Going through the wall.
2. Coming to a stop.
3. Bouncing back.
4. All options are equally dangerous.

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# Newton's laws, kinetic energy, and momentum

For simplicity consider 1D motion and a constant net force F.

Newton's 2nd law: $F = ma, \; a = F/m$

Kinematics: $v_f^2 = v_i^2 + 2a(x_f - x_i) = v_i^2 + 2(F/m)(x_f - x_i)$

Rewrite: $\frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = F(x_f - x_i)$

$\Delta KE = F \cdot d$

Newton's 2nd law is equivalent to the work-kinetic energy theorem.

Assume two objects are interacting and no external forces are present.

Newton's 3rd law: $F_{1\ on\ 2} = -F_{2\ on\ 1}, \; F_{12}\Delta t = -F_{21}\Delta t$

Momentum definition: $\Delta p_2 = -\Delta p_1$

Conservation law: $\Delta p_2 + \Delta p_1 = \Delta p_{total} = 0$

Newton's 3rd law is equivalent to the statement that the total momentum of isolated systems is conserved.

# Conservation of momentum

For a system of objects, a component of the momentum along a chosen direction is constant, if no net outside force with a component in this chosen direction acts on the system.

**In collisions between isolated objects momentum is always conserved.**

$$m_1\mathbf{v}_{1i} + m_2\mathbf{v}_{2i} = m_1\mathbf{v}_{1f} + m_2\mathbf{v}_{2f}$$

**Kinetic energy is only conserved in elastic collisions.**

$$(1/2)m_1v_{1i}^2 + (1/2)m_2v_{2i}^2 = (1/2)m_1v_{1f}^2 + (1/2)m_2v_{2f}^2$$

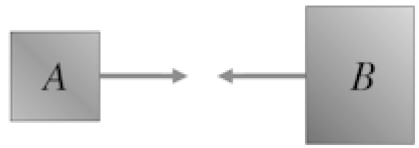
**In explosions or disintegrations momentum is conserved.**

$$(\sum m_iv_i)_{before} = (\sum m_iv_i)_{after}$$

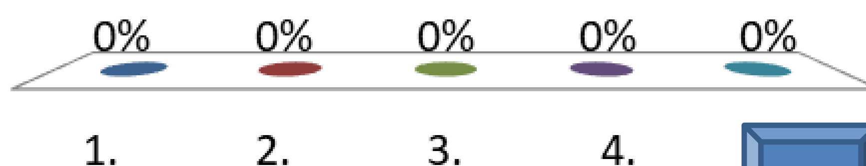
**Kinetic energy is not conserved.**

Stored potential energy is converted into ordered or disordered kinetic energy.

Two objects with different masses collide and stick to each other. Compared to before the collision, the system of two objects after the collision has




1. the same total momentum and the same total kinetic energy.
2. the same total momentum but less total kinetic energy.
3. less total momentum but the same total kinetic energy.
4. less total momentum and less total kinetic energy.
5. not enough information given to decide.

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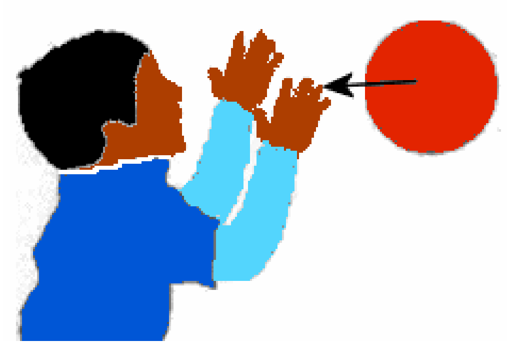
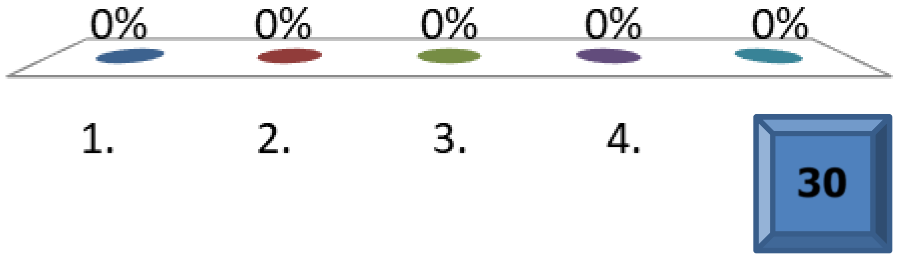
A boy has a mass of 30 kg.  He is standing on an icy pond, when a "friend" throws a 2 kg ball at him with horizontal velocity of  8 m/s.

If the boy catches the ball, how fast will he be moving?

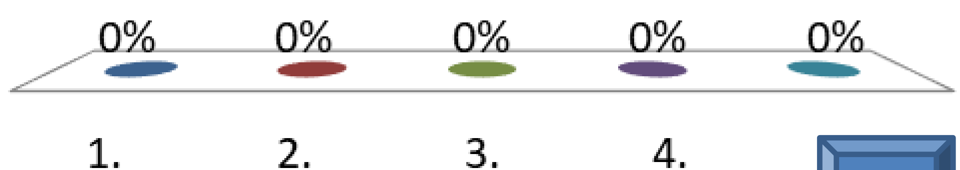


1. 0 m/s
2. 1.88 m/s
3. 0.5 m/s
4. 0.53 m/s
5. 2 m/s



A 65 kg physics student is at rest on a 5 kg sled that also holds a chunk of ice with a mass of 1.5 kg. The student throws the ice horizontally with a speed of 10 m/s relative to the ground. If the sled slides over a frozen pond without friction, how fast (in m/s) are the sled and student traveling with respect to the ground after throwing the chunk of ice?

1. 0.23 m/s
2. 0.327 m/s
3. 5 m/s
4. 0.65 m/s
5. 0.214 m/s

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# Demonstrations

Collisions and conservation of momentum

Newton's cradle

http://www.youtube.com/watch?v=mFNe_pFZrsA

Astroblaster

http://www.youtube.com/watch?v=cloY0R5mj2s&feature=related

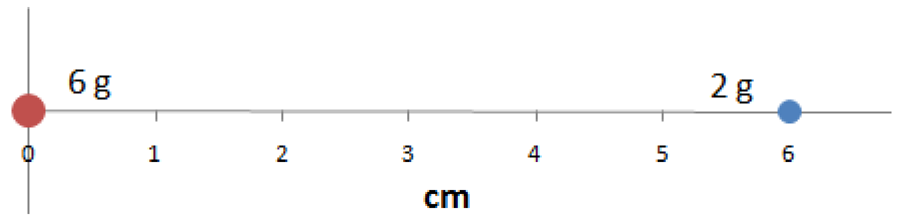
# Center of mass

- The center of mass (CM) of a system moves as if the total mass of the system were concentrated at this special point.
- It responds to external forces as if the total mass of the system were concentrated at this point.
- The total momentum of the system only changes, if external forces are acting on the system.
- The center of mass of the system only accelerates, if external forces are acting on the system.
- Coordinates of the center of mass (CM):

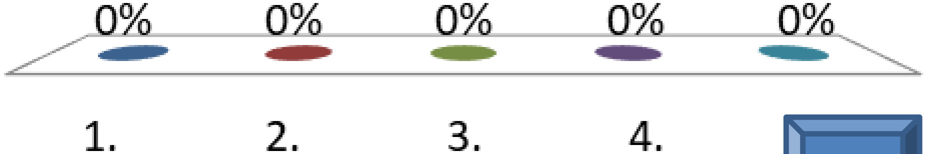
$$x_{CM} = \frac{\sum m_i x_i}{M}, \quad y_{CM} = \frac{\sum m_i y_i}{M}, \quad z_{CM} = \frac{\sum m_i z_i}{M}$$

$$M = \sum m_i$$

Two particles of masses 2 g and 6 g are separated by a distance of 6 cm. The distance of their center of mass from the heavier particle is




1. 1.5 cm
2. 2 cm
3. 3 cm
4. 4 cm
5. 4.5 cm

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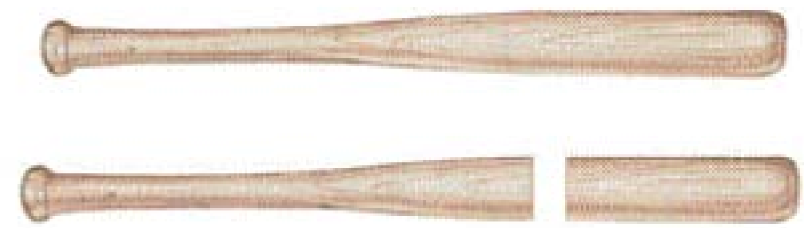
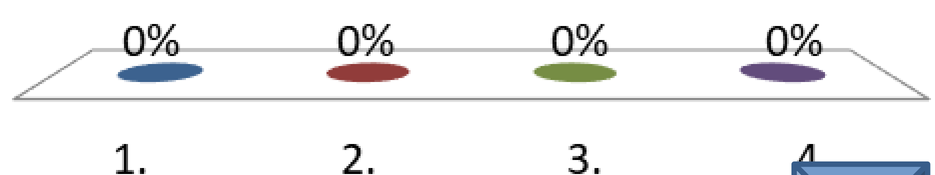
A baseball bat with uniform density is cut at the location of its center of mass as shown in the figure.
The piece with the smaller mass after the cut is



1. the piece on the left.
2. the piece on the right.
3. Both pieces have the same mass.
4. This is impossible to determine.

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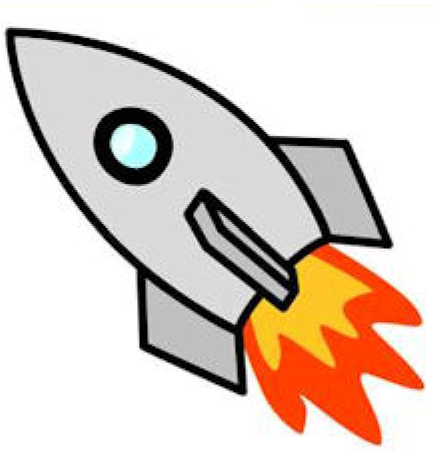
# The rocket principle

System consisting of many parts:
no external force ←→ no acceleration of the CM

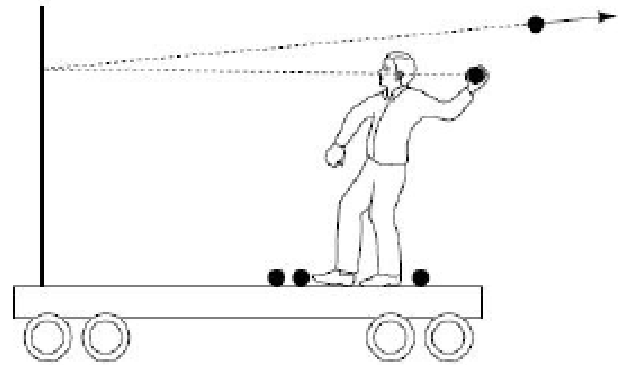
But different parts of the system can accelerate with respect to the CM, as long as the total momentum of the system is constant.

Examples:

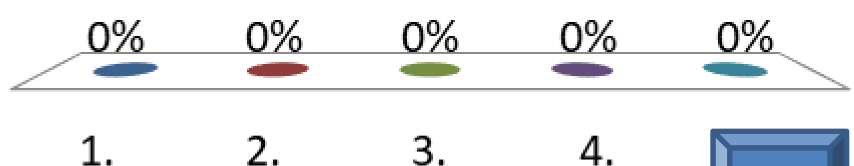


http://www.youtube.com/watch?v=D-5TovPg4F4

Suppose you are on a cart, initially at rest on a frictionless, horizontal track. You throw a series of identical balls against a wall that is rigidly mounted to the cart. If the balls are thrown at a steady rate and bounce straight back, is the cart put into motion?



1. Yes, it starts to move to the right with constant speed.
2. Yes, it starts to move to the right and steadily gains speed.
3. Yes, it starts to move to the left with constant speed.
4. Yes, it starts to move to the left and steadily gains speed.
5. No, it remains in place.

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