NAME: _____ AP PHYSICS 1 DATE: _____

MOMENTUM DAY 2: VECTOR MOMENTUM

MOMENTUM IS A VECTOR

SIGN CONVENTION

In 1D problems, we pick a positive direction (usually right or up).

Moving right	Moving left
$v > 0 \rightarrow p > 0$	$v < 0 \rightarrow p < 0$

Key insight: When an object reverses direction, its momentum changes sign. This makes Δp much larger than if it just stopped!

WE DO **Stopping vs. Bouncing**

A 2.0 kg ball moving at +10 m/s hits a wall. Compare two cases:

Case	p_i	p_f	$\Delta p = p_f - p_i$	Impulse J
Sticks $v_f = 0$				
Bounces $v_f = -10$ m/s				

Conclusion: Bouncing requires _____ the impulse of stopping!

The 2× Rule: When an object bounces elastically (same speed, opposite direction), the impulse is **twice** what it would be to just stop it: $J_{\text{bounce}} = 2mv$

WHY BOUNCING = 2×

VISUALIZE **Momentum Vectors**

Draw momentum vectors for a ball bouncing off a wall (take rightward as positive):

Before (moving right):

$\vec{p}_i = +20$ kg·m/s

After (moving left):

$\vec{p}_f = -20$ kg·m/s

Change in momentum: $\Delta\vec{p} = \vec{p}_f - \vec{p}_i = (-20) - (+20) =$ _____ kg·m/s

APPLYING THE VECTOR APPROACH

WE DO **Ball Bouncing Off Floor**

A 0.50 kg ball falls and hits the floor at 8.0 m/s (downward), then bounces up at 6.0 m/s.

Take **up as positive**.

a) Find initial momentum:

(downward → negative)

b) Find final momentum:

(upward → positive)

c) Find impulse $J = \Delta p$:

d) If contact time is 0.020 s, find F_{avg}:

Notice: The impulse isn't simply $m\times$ (sum of speeds). You must use the vector definition: $\Delta p = p_f - p_i$.

YOU DO **Tennis Ball Hitting Racket**

A 0.058 kg tennis ball approaches a racket at 30 m/s (to the left) and leaves at 40 m/s (to the right). Take **right as positive**.

a. What is the ball's initial momentum? _____ kg·m/s

b. What is the ball's final momentum? _____ kg·m/s

c. What is the impulse delivered to the ball? _____ kg·m/s

d. If contact lasts 0.005 s, what is the average force? _____ N

COMPARING IMPULSE SCENARIOS

SKILL **Ranking Impulse**

All objects below have mass 1.0 kg and initial speed 5.0 m/s (rightward). Rank the **magnitude** of impulse from greatest to least.

Case	Description	v_i	v_f	$\lvert\Delta p\rvert$
A	Stops (sticks to wall)	+5	0	
B	Bounces (same speed)	+5	−5	
C	Speeds up (pushed)	+5	+8	
D	Partially bounces	+5	−2	

Ranking: _____ > _____ > _____ > _____

REAL-WORLD CONNECTIONS

WHY BOUNCING MATTERS

Many safety and sports applications depend on understanding bouncing vs. stopping:

- **Bulletproof vests:** Some catch the bullet (stop), others deflect it (partial bounce). Which is harder on the wearer?
- **Car crashes:** A head-on collision where cars bounce apart vs. crumple together—which has greater impulse?
- **Water hoses:** Firefighters use spray nozzles that make water bounce back, increasing the reaction force — up to double if the water rebounds at the same speed.

ANALYSIS **Firefighter Nozzle**

A fire hose sprays 20 kg of water per second at a wall at 25 m/s. The water bounces back at 5.0 m/s.

a) Find the impulse per second delivered to the wall.

Hint: In 1 second, 20 kg of water changes velocity from +25 to −5.

b) What force does the water exert on the wall?

Hint: Force = impulse per unit time.

YOU DO **Catching vs. Bouncing**

A 0.40 kg ball moving at 12 m/s is either caught (stopped) or hit back at 12 m/s. The contact time is 0.050 s in both cases.

Catching (stops):

Impulse = _____ N·s

Force = _____ N

Hitting back (bounces):

Impulse = _____ N·s

Force = _____ N

SUMMARY

KEY TAKEAWAYS

- Momentum is a **vector**—direction matters!
- Use signs consistently: pick + direction, stick with it.
- Bouncing back at the same speed requires **twice the impulse** of stopping.
- Always calculate $\Delta p = p_f - p_i$, not just change in speed.

HOMEWORK

3 Vertical Bounce

A 0.60 kg ball is dropped and hits the floor at 7.0 m/s (downward), bouncing up at 5.0 m/s.

a. Taking upward as positive, find p_i, p_f, and Δp.

b. If contact lasts 0.015 s, what is the average force on the ball?

c. How does this force compare to the ball's weight? (Express as a multiple of mg.)

4 Conceptual: Vest Design

Some bulletproof vests are designed to stop bullets inside the vest. Others use ceramic plates that shatter and can deflect bullets slightly backward. Which design subjects the wearer to greater impulse? Explain your reasoning.

5 AP-Style Multiple Choice

A ball of mass m moving at speed v bounces off a wall, returning at the same speed. What is the magnitude of the impulse delivered to the ball?

(A) 0 (B) mv (C) $\frac{3}{2}mv$ (D) $2mv$

Answer: _____ **Explain:**