In your work, please remember to

1) Draw pictures and/or diagrams of the situation before beginning a solution
2) Write down the known quantities and the desired unknown(s)
3) Start your solution by writing down a fundamental relation or equation that you think is relevant.

Equations and Relations:

Motion with Constant Acceleration:

$$v = v_0 + at$$

$$x = x_0 + v_0 t + \frac{1}{2} at^2$$

$$v^2 = v_0^2 + 2a(x - x_0)$$
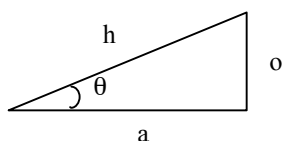
$$g = 9.80 m/s^2 \approx 10 m/s^2$$

Trigonometry:

$\sin \theta = o/h$

$\cos \theta = a/h$

$\tan \theta = o/a$

$a^2 + o^2 = h^2$

Newton's Laws:

• 1st: An object will stay at rest or in motion with constant velocity unless acted on by a net force.

• 2nd: $\Sigma F_x = ma_x$, $\Sigma F_y = ma_y$

• 3rd: Forces come in pairs. If A exerts a force on B, then B exerts a force on A with the same magnitude but in the opposite direction.

Weight: $W = mg$

Friction: $f_s \leq \mu_s N$, $f_k = \mu_k N$

Circular Motion: $a_c = v^2 / r$

Momentum: $\vec{p} = m\vec{v}$, $\Sigma \vec{F} = \frac{\Delta \vec{p}}{\Delta t}$

1. Discuss as a group what the terms "conserve" , "momentum" and "conservation of momentum" mean. Write your group's consensus definitions of the terms down on paper or a whiteboard.

2. Maria and Shawn are ice skating when Maria decides to throw a snowball at Shawn. She stops near him and throws the snowball *horizontally* as hard as she can.

    (a) Make a free-body diagram (FBD) *for the snowball while Maria is throwing it* (while her arm is moving forward with the snowball in her hand). Is there a net force on the snowball during this time?
    (b) Make a FBD *for Maria while she is throwing the snowball.* Is there a net force on her during this time? You can neglect friction between her skates and the ice.

Check Point
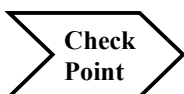
    (c) Group your two previous FBDs together by drawing a single large circle around both. Is there a net force on this *entire system* while Maria is throwing the snowball?
    (d) Answer the following questions by referring to parts a)—c) above.

        i)   Is the momentum of the snowball conserved as Maria throws it?
        ii)   Is Maria's momentum conserved as she throws the snowball?
        iii)   Is the momentum of the system of Maria plus the snowball conserved?

    Don't erase your diagrams, because you will continue to analyze the same situation in the next problem.

Check Point
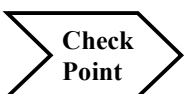
3. In the previous problem, you should have concluded that for the system of *Maria plus the snowball*, momentum is conserved as she throws the snowball. Now let's see how to use that information to determine what happens to Maria after she throws the snowball. You will need the following information: Maria's mass is 50 kg, the mass of the snowball is ½ kg, and the snowball leaves her hand at a speed of 20 m/s.

    (a) Make 2 sketches, one representing the "initial state" (before the snowball is thrown) and one representing the "final state" (just after the snowball is thrown). Label the initial and final velocities of both Maria and the snowball with appropriate symbols.

    (b) Write an equation (symbols only) for the conservation of momentum for Maria and the snowball in the horizontal direction.

    (c) Solve this equation algebraically (still without numbers) for the final velocity of Maria after the throw.

    (d) Use the given information to determine Maria's actual velocity just after she releases the snowball.

> **Check Point**

4. For each situation below, draw a FBD for each object *during the interaction described* and then state whether momentum is conserved exactly, conserved approximately, or not conserved at all during the interaction.

    (a) While taking a walk outside a space station far from Earth, an astronaut loses her grip and drifts off into space. In an effort to get back to safety, she throws a massive wrench in the direction opposite the station. Make your FBDs for the time during which the astronaut is throwing the wrench.

        (i)   Is momentum conserved for the wrench?
        (ii)   Is momentum conserved for the astronaut?
        (iii)   Is momentum conserved for the wrench/astronaut system?

    (b) A tennis ball hits a wall and bounces off. Make your FBDs for the time during which the ball is colliding with the wall.

        (i)   Is momentum conserved for the ball?
        (ii)   Is momentum conserved for the wall?
        (iii)   Is momentum conserved for the system consisting of the ball and the wall?

    (c) A bumper car collides with another bumper car from behind, and both cars end up sliding to the right. Friction between the car tires and the ground is small, but not zero. Make your FBDs for the time during which the cars are colliding with each other.

        (i)   Is momentum conserved for each bumper car individually?
        (ii)   Is momentum conserved for the system consisting of both bumper cars?

> **Check Point**

5. You are relaxing after a delicious Japanese meal by watching some sumo wrestling on TV. You observe that two sumo wrestlers typically run horizontally at each other, collide and *stick together*, and you decide to analyze such a collision to practice your physics. The masses and initial speeds of a particular pair of wrestlers are shown on the diagram below. During their collision, the only horizontal forces acting on the two wrestlers are the forces they exert on each other.

mass = 100 kg
speed = 2 m/s

mass = 150 kg
speed = 1 m/s
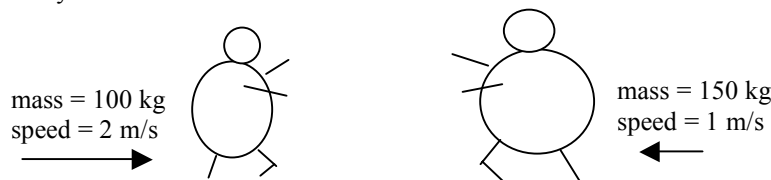
(a) Make a free-body diagram for each wrestler *during their collision*:

(b) Is the *combined* momentum of the two wrestlers conserved during their collision? Clearly explain why or why not.

(c) Determine the speed and direction of the two wrestlers (now stuck together) immediately after their collision.

Check Point

6. At the LA Lakers' basketball arena in Los Angeles, a maintenance man has tried out a new type of floor wax that has unfortunately rendered the floor of the court *completely frictionless*. Shaquille O'Neal has been standing in the middle of the court dreaming of another NBA championship during the waxing process, and is now stranded there. Luckily, he is carrying his NBA Most Valuable Player trophy, which weighs 50 pounds. If O'Neal, who weighs 300 pounds, hurls the trophy away from himself at 6 m/s, how long will it take him to reach the unwaxed edge of the court, 30 meters away?

Check Point

Additional Questions:

1. A satellite powered by a so-called "ion propulsion engine" was recently sent into space. It essentially works by spitting atoms out the back of the engine, which somehow propels the satellite forward. Can you explain how this engine works from the point of view of conservation of momentum? For which system is momentum conserved?

2. Highway patrol officers routinely assume that momentum is conserved during the collisions of automobiles. Explain why you think this is or is not a reasonable assumption.

3. Passengers in cars are required to wear seatbelts, but children in a school bus are not. Can you explain this fact by thinking about momentum?