Momentum Concepts Review Sheet

- Any moving object with mass has momentum. $\vec{p} = m\vec{v}$
- Momentum is a vector. The momentum vector has the same direction as velocity.
- Impulse is the momentum transferred between objects by a force. It can be determined as either the change in momentum or the product of average force and time. $\vec{J} = \Delta\vec{p} = \bar{\vec{F}}t$
- Conservation of momentum for an object can be written as: $\vec{p}_0 + \vec{J} = \vec{p}_f$

<u>Collisions</u>

- All collisions conserve momentum (This is a bit of an idealization that assumes short times for collisions and negligible outside forces, but is a reasonable approximation in most cases.)
- 2+2 Types of Collisions:
  - Elastic = conserve **<u>both</u>** momentum and energy.
    - This is an idealization, but some real-world collisions approach this ideal. Ex. Steel ball bearings of Newton's cradle or billiard balls
  - Inelastic = conserve **<u>only</u>** momentum.
    - Most real-world collisions fall in this category
    - Perfectly inelastic ("sticky") collisions = two objects move together after the collision (have the same velocity). Momentum is conserved; energy is lost.
    - Explosion = "An inelastic collision in reverse;" one object becomes two or more objects. Momentum is conserved; energy is gained. Ex. Rockets, recoil of a gun, jumping off a skateboard
- Conservation of momentum equation: $\vec{p}_0 = \vec{p}_f$
  - For two objects colliding in one dimension: $m_1v_1 + m_2v_2 = m_1v_1' + m_2v_2'$
  - For two objects colliding in two dimensions, conserve momentum by components
    - x-component: $m_1v_{1x} + m_2v_{2x} = m_1v_{1x}' + m_2v_{2x}'$
    - y-component: $m_1v_{1y} + m_2v_{2y} = m_1v_{1y}' + m_2v_{2y}'$
- Conservation of energy equation: $KE_0 = KE_f$
  - In general, for two objects, this is: $\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 = \frac{1}{2}m_1(v_1')^2 + \frac{1}{2}m_2(v_2')^2$
  - For two objects colliding in one dimension, this simplifies to $v_1 - v_2 = v_2' - v_1'$ (approach speed = separation speed)

<u>Force vs. Time Graphs</u>

- Impulse is the area under a force vs. time graph.
  - $\Delta\vec{p} = \bar{\vec{F}}t$
  - This is analogous to $\Delta s = \bar{v}t$ from the beginning of the year. Recall that the change in position is the product average velocity and time or area under a velocity vs. time graph.
- When solving a problem with a force vs. time graph, you are considering momentum for each object independently. Use: $\vec{p}_0 + \vec{J} = \vec{p}_f$ (for **<u>one object at a time</u>**).
- The impulses on each object have the same size, but opposite direction (sign).

Newton's Laws

- Newton's First Law: It takes an impulse to change momentum. Without a new impulse an object's momentum remains constant.
- Newton's Second Law: $\vec{F} = \frac{\Delta \vec{p}}{t}$. For an object with constant mass, this becomes $\vec{F} = \frac{m\Delta \vec{v}}{t} = m\vec{a}$.
- Newton's Third Law: If object A transfers momentum to object B by impulse $\vec{J}$, then object B will transfer the same amount of momentum in the opposite direction $-\vec{J}$ to object A.
  Ex. Object A is moving to the right and collides with object B giving it +20 N·s of momentum (20 N·s to the right). Object B transfers -20 N·s to object A (20 N·s to the left).
  Note that the total momentum change to the **system** (objects A and B together) is zero.

Rockets

- Rockets work by conservation of momentum.
- A rocket must throw spent (burnt) fuel out the back to increase its velocity. For that matter, a thruster that changes the direction of the rocket must expel gas. The exhaust is always in the opposite direction from that which the rocket needs to move or turn. (That is to go forward, thrust should be out the back of the rocket. No kidding, right? To turn left, the thruster should fire to the right.)
- Rockets are sometimes called "reaction drives" from Newton's Third Law "every actions has an equal and opposite reaction."
- Reactionless drives (those that work without conservation of momentum) might be a science fiction staple, but we cannot build one. If you get one to work, this is probably worthy of a Nobel Prize, but Grand Unification is probably easier.