1. What is momentum and how does it relate to forces applied to a body?

   The momentum of a body is equal to the product of the body’s mass times its velocity. The rate of change of momentum of a body is equal to the net force applied to it.

2. State the law of conservation of momentum in both words and an equation.

   The total momentum of an isolated system of bodies remains constant.

   \[ m_1 v_1 + m_2 v_2 = m_1 v_1' + m_2 v_2' \]

3. Which concept is useful for dealing with forces that act over a very short period of time like a bat hitting a baseball?

   Impulse

4. When is a collision considered ‘elastic’?

   When total kinetic energy is conserved.
5. Write the equation for the conservation of kinetic energy in an elastic collision and explain what the subscripts and superscripts mean.

\[ \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2 = \frac{1}{2} m_1 v_1'^2 + \frac{1}{2} m_2 v_2'^2 \]

The subscripts (1 and 2) identify the two different bodies. The superscripts (‘) refer to the velocities after the collision. If the masses also changed they would have these superscripts also.

6. How does an inelastic collision differ from an elastic one?

In an inelastic collision, kinetic energy is not conserved. Some of the energy is lost.

7. What is a completely inelastic collision?

When the two bodies stick together after the collision.

8. Define center of mass.

If a body rotates, or there are several bodies that move relative to one another, there is one point called the center of mass that moves in the same path that a particle would if subjected to the same net force.


General motion of an extended body (or system of bodies) can be considered as the sum of the
translational motion of the CM, plus rotational, vibrational, or other types of motion about the CM.

10. What is the center of gravity?
That point at which the force of gravity can be considered to act.

11. A 213-kg sumo wrestler on the left and his 233-kg opponent on the right, charge each other at a closing speed of 17 m/s. If they hold on to each other during the collision, at what speed and in which direction will they move after the collision?
Assume that each of the wrestlers are going at half the closure speed, equal speed. Since they are coming toward each other, one of their momenta has to be negative.

\[
m_1v_1 - m_2v_2 = (m_1 + m_2)v_x
\]

\[
m_1v_1 - m_2v_2 \quad \frac{(m_1 + m_2)}{213(8.5) - (233)(8.5)} = v_x = -0.38 m/s, \text{ to the left}
\]

12. A girl riding a skateboard at 5.00 m/s throws a 1.50-kg soccer ball to a friend at 18.0 m/s. The friend is directly in front of the girl and in the path she is travelling. If the girl and the skateboard have a combined mass of 60.0-kg, how fast and in what direction will she move after the throw? Assume no friction.
\[
m_c v_c + m_2 v_x = m_1 v_1' + m_2 v_2'
\]
\[
m_c v_c - m_2 v_2' = m_1 v_1'
\]
\[
\frac{m_c v_c - m_2 v_2'}{m_1} = v_1'
\]
\[
\frac{(61.5)(5)-(1.5)(18)}{60} = v_1' = 4.68 \text{m/s in the same direction}
\]

13. The average leg speed of an NFL soccer-style kicker is 18.3 m/s. If the 0.415-kg football leaves the tee at 15.6 m/s and the kicker’s foot is in contact with the ball for 0.007s, what was the force with which the kicker kicked the ball.

\[\text{Impulse} = F \Delta t = \Delta p, \text{ you can do this by just evaluating the impulse on the football}\]

\[F \Delta t = m v_2 - m v_x\]

\[F = \frac{m v_1}{\Delta t} = \frac{(0.415)(15.6)}{(0.007)} = 925 \text{N}\]

14. The 1200-kg rocket Nissan Frontier was doing 80 km/hr down the right lane of 5\textsuperscript{th} Ave the other day when a Canadian tourist in a 2100-kg Cadillac doing 40 km/hr decided to change lanes without looking. The Frontier rear-ended the Cadillac, but luckily it was a perfectly elastic collision. What was the speed of the two cars after the collision and how long did the Canadian have his left turn-signal on prior to the collision?
\[
\frac{80 \text{ km}}{\text{hr}} = 22 \frac{\text{m}}{\text{s}} \\
\frac{40 \text{ km}}{\text{hr}} = 11 \frac{\text{m}}{\text{s}} \\
\nu_1 - \nu_2 = -(\nu_1' - \nu_2') = \nu_2' - \nu_1' \\
11 + \nu_1' = \nu_2' \\
\text{ } \\
m_1\nu_1 + m_2\nu_2 = m_1\nu_1' + m_2\nu_2' \\
m_1\nu_1 + m\nu_2 = m_1\nu_1' + m_2(11 + \nu_1') \\
\text{ } \\
m\nu_1 + m\nu_2 = m_1\nu_1' + 11m_2 + m_2\nu_1' \\
m\nu_1 + m\nu_2 - 11m_2 = m_1\nu_1' + m_2\nu_1' \\
\text{ } \\
m\nu_1 + m\nu_2 - 11m_2 = (m_1 + m_2)\nu_1' \\
\frac{m\nu_1 + m\nu_2 - 11m_2}{(m_1 + m_2)} = \nu_1' \\
\frac{(1200)(22) + (2100)(11) - 11(2100)}{(1200 + 2100)} = \nu_1' \\
= 8.00 \text{ m/s} \\
\text{ } \\
11 + \nu_1' = \nu_2' \\
\text{ } \\
11 + 8 = \nu_2' = 19 \text{ m/s} \\
\text{Check your work} \\
\nu_1 - \nu_2 = -(\nu_1' - \nu_2') = \nu_2' - \nu_1' \\
22 - 11 = 19 - 8 \sqrt{ \text{ } } \\
m_1\nu_1 + m_2\nu_2 = m_1\nu_1' + m_2\nu_2'
15. A 7.27-kg bowling ball is rolled down the alley at 15 m/s to pick up a spare, which it does. The collision is perfectly elastic and the bowling ball’s speed after the collision was 13.5 m/s. What is the mass of the pin and what was it’s speed after the collision?

\[ v_1 - v_2 = -(v_1' - v_2') = v_2' - v_1' \]
\[ v_1 - v_2 = v_2' - v_1' \]
\[ 15 + 13.5 = v_2' = 28.5 \]
\[ m_1v_1 + m_2v_2 = m_1v_1' + m_2v_2' \]
\[ m_1v_1 - m_1v_1' = m_2v_2' \]
\[ \frac{m_1v_1 - m_1v_1'}{v_2'} = m_2 \]
\[ \frac{(7.27)(15) - (7.27)(13.5)}{(28.5)} = m_2 = 0.38 \text{ kg} \]

**Check your work**

\[ v_1 - v_2 = v_2' - v_1' \]
\[ 15 = 28.5 - 13.5 \sqrt{ } \]
\[ m_1v_1 + m_2v_2 = m_1v_1' + m_2v_2' \]
\[ (7.27)(15) = (7.27)(13.5) + (0.38)(28.5) \]
\[ 109 = 109 \sqrt{ } \]
16. When radium decays into radon and an alpha particle \((^{226}_{88}Ra \to ^{222}_{86}Rn + ^4_2\alpha)\), 1.01 \times 10^{-11} \text{ J} \) of energy is released. Assuming the radium atom is initially at rest and that all of the released energy is translated into the kinetic energy of the decay products, what will be their respective speeds? Masses are: \(\text{Ra} – 3.75 \times 10^{-25} \text{ kg}, \text{Rn} – 3.69 \times 10^{-25} \text{ kg}, \alpha – 6.64 \times 10^{-27} \text{ kg}.

\[
\begin{align*}
m_1 v_1 + m_2 v_2 &= m_1 v_1' + m_2 v_2' \\
-m_2 v_2' &= m_1 v_1' \quad (1) \\
-m_2 v_2' &= \frac{m_1}{m_2} v_1' \quad (2) \\
-0.0180 v_2' &= v_1' \quad (3) \\
1.01 \times 10^{-11} &= \frac{1}{2} m_1 v_1'^2 + \frac{1}{2} m_2 v_2'^2 \quad (4)
\end{align*}
\]

\[
\begin{align*}
1.01 \times 10^{-11} &= \frac{1}{2} (3.69 \times 10^{-25})(-0.0180 v_2')^2 \\
&\quad \quad + \frac{1}{2} (6.64 \times 10^{-27}) v_2'^2 \quad (5)
\end{align*}
\]

\[
\begin{align*}
1.01 \times 10^{-11} &= (5.98 \times 10^{-29}) v_2'^2 + (3.32 \times 10^{-27}) v_2'^2 \\
&= (5.98 \times 10^{-29}) v_2'^2 + (3.32 \times 10^{-27}) v_2'^2
\end{align*}
\]
1. A 1400-kg car travelling at 17 m/s collides with an 1100 kg car going in the opposite direction at 15 m/s. The cars stay locked together after the collision. Assuming no friction, how much energy was lost in the collision?

Energy lost is energy after collision minus energy before collision. Energy before the collision is the sum of the kinetic energies of the two cars. Energy after the collision is kinetic energy of two cars locked together, both travelling at a speed you have to figure out.

\[ m_1 v_1 - m_2 v_2 = (m_1 + m_2)v_x \]

(Minus because the second car was going in the opposite direction)

\[ \frac{m_1 v_1 - m_2 v_2}{(m_1 + m_2)} = v_x \]
\[
\frac{(1400)(17) - (1100)(15)}{(1400 + 1100)} = v_x = 2.92 \text{ m/s}
\]

\[
KE = \frac{1}{2}mv^2
\]

\[
KE_1 = \frac{1}{2}(1400)(17)^2 = 2.02 \times 10^5 J
\]

\[
KE_2 = \frac{1}{2}(1100)(15)^2 = 1.24 \times 10^5 J
\]

\[
KE_{1+2} = \frac{1}{2}(1400 + 1100)(2.92)^2 = 1.07 \times 10^4 J
\]

\[
KE_{1+2} - (KE_1 + KE_2) = 1.07 \times 10^4 J - (2.02 \times 10^5 J + 1.24 \times 10^5 J)
\]

\[
= -3.15 \times 10^5 J
\]

18. A weightlifter mistakenly puts 20-kgs on one end of a 2m bar and 25-kgs on the other. How far from the center of the bar will the center of mass be?

Since you want to find distance point from the center, I would make the reference point the center of the bar. The 20kg weight would then be a distance of -1m from the center and the 25kg weight would be +1m from the center.

\[
\chi_{CM} = \frac{m_1x_1 + m_2x_2}{m_1 + m_2}
\]
\[ x_{CM} = \frac{(20)(-1) + (25)(+1)}{20 + 25} = 0.11\text{m} \text{ to the right of center (towards the heavier weight)} \]

19. What is the center of mass of an average person who is 6ft tall (1.58m)? Use the floor as your reference point.

\[ y_{CM} = \frac{m_1y_1 + m_2y_2}{m_1 + m_2} \]

\[ y_{CM} = \frac{(3.4)(1.8) + (9.6)(18.2) + (21.5)(42.5) + (1.7)(43.1)}{(3.4) + (9.6) + (21.5) + (1.7)} = \frac{5796.2}{100} = 57.962\% \times 1.58 = 0.916\text{m} \]