9-7 In the ammonia (NH₃) molecule (see Fig. 9-26), the three hydrogen (H) atoms form an equilateral triangle; the center of the triangle is $9.40 \times 10^{-11} \text{ m}$ from each hydrogen atom. The nitrogen (N) atom is at the apex of a pyramid, with the three hydrogen atoms forming the base. The nitrogen-to-hydrogen atomic mass ratio is 13.9, and the nitrogen-to-hydrogen distance is $10.14 \times 10^{-11} \text{ m}$. Locate the center of mass of the molecule relative to the nitrogen atom.

Call the perpendicular distance to the plane of the three hydrogen atoms $l$.

Note that the CM (center of mass) must lie along this line.

Also, the CM of the H-atoms alone must be at the pt. where this line, $l$, intersects the plane.

Then, $l = \sqrt{(10.14 \times 10^{-11})^2 - (9.40 \times 10^{-11})^2}$

$l = 3.803 \times 10^{-11} \text{ m}$

So, \[ y = \text{distance above H plane} \]
\[ y = \frac{m_N}{3m_H + m_N} \times l \]

Distance from Nitrogen is
\[ l - y = \left(1 - \frac{m_N}{3m_H + m_N}\right) l = \frac{3m_N}{3m_H + m_N} l \]

\[ l - y = \frac{3}{3 + \frac{m_N}{m_H}} l = \frac{3}{8 + 13.9} (3.803 \times 10^{-11} \text{ m}) \]

\[ l - y = 0.675 \times 10^{-11} \text{ m} \] from Nitrogen atom
9-12 A man of mass \( m \) clings to a rope ladder suspended below a balloon of mass \( M \); see Fig. 9-29. The balloon is stationary with respect to the ground.
(a) If the man begins to climb the ladder at speed \( v \) (with respect to the ladder), in what direction and with what speed (with respect to the ground) will the balloon move?
(b) What is the state of the motion after the man stops climbing?

---

9-12. The balloon + man system is stationary (since we are told that the balloon is stationary when the man is not climbing.)

\[
\begin{align*}
\text{Balloon} & \quad \text{(velocity of man with respect to ladder)} \\
\text{Man} & \quad \text{(velocity of man with respect to ladder)} \\
\text{Ground} & \quad \text{(motion of balloon)}
\end{align*}
\]

See sketch. Let velocity of the balloon with respect to the ground be \( U \).

The ladder moves with the same velocity as the balloon = \( U \).

Call \( v_g \) = velocity of man with respect to ground.

Then \( v_g = v - U \)

Since the entire system has no force = no acceleration and \( v_{\text{com}} = 0 \) before he climbed,
then \( v_{\text{com}} = 0 \) when he climbs --- (no external forces)

\[
v_{\text{com}} = \frac{m v_g - M U}{m + M} = 0
\]

Hence, \( U = \frac{m}{M} v_g = \frac{m}{M} (v - U) \Rightarrow U \left(1 + \frac{M}{m}\right) = \frac{m}{M} v
\]

\[
U = \frac{m v}{m + M}
\]

(b) This relation is general. So, if man stops climbing \((v = 0)\), then \( U = 0 \) so balloon returns to being stationary.
9-24 A 0.165 kg cue ball with an initial speed of 2.00 m/s bounces off the rail in a game of pool, as shown from an overhead view in Fig. 9-33. For x and y axes located as shown, the bounce reverses the y component of the ball's velocity but does not alter the x component.

(a) What is \( \theta \) in Fig. 9-33?

(b) What is the change in the ball's linear momentum in unit-vector notation? (The fact that the ball rolls is not relevant to either question.)

\[
\begin{align*}
\text{Momentum components of ball before hitting rail:} \\
\text{a)} \quad P_x &= mv_x \sin \theta = (0.165)(2.00)(\sin 30^\circ) \\
\text{b)} \quad P_y &= mv_y \cos \theta \\
\text{c)} \quad P_x' &= mv_x' \sin \theta = (0.165)(2.00)(\sin 30^\circ) \\
\text{d)} \quad P_y' &= mv_y' \cos \theta \\
\end{align*}
\]

\[
\begin{align*}
\Delta P_x &= P_x' - P_x = -mv_x \cos \theta = -mv_y \sin \theta \\
\Delta P_y &= -2mv_x \cos \theta = -2(0.165)(2.00)(\cos 30^\circ) \\
\Delta P_y' &= -0.572 \text{ kg m/s} \\
\text{So, } \Delta P_y &= -0.572 j \text{ kg m/s}
\end{align*}
\]
9-38 An object, with mass \( m \) and speed \( v \) relative to an observer, explodes into two pieces, one three times as massive as the other; the explosion takes place in deep space. The less massive piece stops relative to the observer. How much kinetic energy is added to the system in the explosion, as measured in the observer's reference frame?

The conservation of momentum is applicable since all forces occurring during the explosion are internal to the system. Along the x-axis:

\[
mv = \left( \frac{m}{4} \right) 0 + \left( \frac{3m}{4} \right) v' 
\]

So

\[
v' = \frac{4}{3} v 
\]

So, kinetic energy after wards is

\[
K_{after} = \frac{1}{2} \left( \frac{3m}{4} \right) (v')^2 = \frac{3}{8} m \left( \frac{4}{3} v \right)^2 = \frac{3}{8} \frac{16}{9} mv^2 
\]

Whereas

\[
K_{before} = \frac{1}{2} mv^2 
\]

\[
\Delta K = K_{after} - K_{before} = \left( \frac{2}{3} - \frac{1}{2} \right) mv^2 = \left( \frac{4}{3} - \frac{3}{2} \right) mv^2 = \frac{1}{6} mv^2 
\]

(added by explosion)
9-42 A rocket is moving away from the solar system at a speed of $6.0 \times 10^3$ m/s. It fires its engine, which ejects exhaust with a speed of $3.0 \times 10^3$ m/s relative to the rocket. The mass of the rocket at this time is $4.0 \times 10^4$ kg, and its acceleration is $2.0$ m/s$^2$.

(a) What is the thrust of the engine?

(b) At what rate, in kilograms per second, is exhaust ejected during the firing?

\[ T = \frac{dM}{dt} \]

\[ \text{where } V_r = \text{velocity of expelled gas related to the rocket} \]

\[ M = \text{mass of rocket} \]

\[ \frac{dM}{dt} = \text{rate of expelled mass loss} \]

(a) So

\[ T = M \frac{dv_r}{dt} = (4.0 \times 10^4)(2.0) = 8.0 \times 10^4 \text{ Newtons} \]

(b) Since

\[ \frac{dM}{dt} = \frac{T}{V_r} = \frac{8.0 \times 10^4 \text{ Newtons}}{3.0 \times 10^3 \text{ m/s}} \]

\[ \frac{dM}{dt} = 26.7 \text{ kg/s} \]
10-2 The National Transportation Safety Board is testing the crash-worthiness of a new car. The 2300 kg vehicle, moving at 15 m/s, is allowed to collide with a bridge abutment, which stops it in 0.56 s. What is the magnitude of the average force that acts on the car during the impact?

\[
F_{av} = \frac{M \Delta v}{\Delta t} = (2300 \text{ kg}) \left( \frac{15 \text{ m/s}}{0.56 \text{ s}} \right) = 6.2 \times 10^4 \text{ Newtons}
\]

[Note, average acceleration is \( \frac{F_{av}}{m} = 26.8 \text{ m/s}^2 \) or \( 2.7 \text{ g} \)].

10-16 A ball having a mass of 150 g strikes a wall with a speed of 5.2 m/s and rebounds with only 50% of its initial kinetic energy.

(a) What is the speed of the ball immediately after rebounding?

(b) What is the magnitude of the impulse on the wall from the ball?

(c) If the ball was in contact with the wall for 7.6 ms, what was the magnitude of the average force on the ball from the wall during this time interval?

\( m = 0.150 \text{ kg} \quad v_1 = 5.2 \text{ m/s} \)

\[
K_1 = \frac{1}{2} m v_1^2 \quad K_2 = \frac{1}{4} m v_1^2 = \frac{1}{2} m v_2^2
\]

\[
S_o \quad v_1 = \frac{1}{2} v_1^2 \quad v_2 = \frac{1}{2} v_1 \quad v_1 = \frac{1}{\sqrt{2}} (5.2 \text{ m/s})
\]

\( v_1 = 3.67 \text{ m/s} \)

(b) The impulse applied by the wall on the bullet, and vice-versa

\[
F_{av} = \frac{m \Delta v}{\Delta t} = \frac{m}{\Delta t} (v_1 - v_2) = \frac{0.150}{7.6 \times 10^{-3} \text{ s}} (5.2 - (-3.67))
\]

\( F_{av} = 175 \text{ Newtons} \)
A 5.20 g bullet moving at 672 m/s strikes a 700 g wooden block at rest on a frictionless surface. The bullet emerges, traveling in the same direction with its speed reduced to 428 m/s.

(a) What is the resulting speed of the block?
(b) What is the speed of the bullet–block center of mass?

\[ m \mathbf{v}_0 = M \mathbf{v}_M + m \mathbf{v}_m \]

\[ v_M = \frac{m}{M} (v_0 - v_m) = \frac{0.0052 \text{ kg}}{0.7 \text{ kg}} (672 - 428) \text{ m/s} \]

\[ v_M = 1.81 \text{ m/s} \]

(b) The center of mass is the same before and after collision.

\[ (m + M) v_{CM} = m v_0 \]

\[ v_{CM} = \frac{m}{m+M} v_0 = \frac{0.0052}{0.705} (672) = 49.6 \text{ m/s} \]