5. *A runaway train car that has a mass of 15,000 kg travels at a speed of* $5.4\,\text{m/s}$ *down a track. Compute the time required for a force of 1500 N to bring the car to rest.*

Solution $\Delta p = \text{net } F\Delta t$ so $\Delta t = \dfrac{\Delta p}{\text{net}F} = \dfrac{15{,}000\text{ kg}(5.4\text{ m/s})}{(1500\text{ N})} = \underline{54\text{ s}}$ to stop the car.

7. *A bullet is accelerated down the barrel of a gun by hot gases produced in the combustion of gun powder. What is the average force exerted on a 0.0300-kg bullet to accelerate it to a speed of 600.0 m/s in a time of 2.00 ms (milliseconds)?*

Solution

$$\text{net F} = \frac{\Delta p}{\Delta t} = \frac{m\Delta v}{\Delta t} = \frac{0.0300\text{ kg}\times 600.0\text{ m/s}}{2.00\times 10^{-3}\text{s}} = \underline{9.00\times 10^{3}\text{ N}}$$

12. ***Professional Application*** *One hazard of space travel is debris left by previous missions. There are several thousand objects orbiting Earth that are large enough to be detected by radar, but there are far greater numbers of very small objects, such as flakes of paint. Calculate the force exerted by a 0.100-mg chip of paint that strikes a spacecraft window at a relative speed of* $4.00\times 10^{3}\text{ m/s}$*, given the collision lasts* $6.00\times 10^{-8}\text{ s}$.

Solution

$$\text{net } F = \frac{\Delta p}{\Delta t} = \frac{m\Delta v}{\Delta t} = \frac{\left(1.00\times 10^{-4}\text{ kg}\right)\left(4.00\times 10^{3}\text{ m/s}\right)}{6.00\times 10^{-8}\text{ s}} = \underline{6.67\times 10^{6}\text{ N}}$$

(assuming the chip sticks to the spacecraft)

15. *A cruise ship with a mass of* $1.00\times 10^{7}\text{ kg}$ *strikes a pier at a speed of 0.750 m/s. It comes to rest 6.00 m later, damaging the ship, the pier, and the tugboat captain's finances. Calculate the average force exerted on the pier using the concept of impulse. (Hint: First calculate the time it took to bring the ship to rest.)*

Solution

$$\Delta x = \bar{v}\Delta t = \frac{1}{2}\left(v+v_0\right)\Delta t \text{ so that } \Delta t = \frac{2\Delta x}{v+v_0} = \frac{2\left(6.00\text{ m}\right)}{\left(0+0.750\right)\text{m/s}} = \underline{16.0\text{ s.}}$$

$$\text{net } F = \frac{\Delta p}{\Delta t} = \frac{m\left(v-v_0\right)}{\Delta t} = \frac{\left(1.00\times 10^{7}\text{ kg}\right)\left(0-0750\right)\text{m/s}}{16.0\text{ s}} = \underline{-4.69\times 10^{5}\text{ N.}}$$

So, by Newton's third law, the net force on the pier is $\underline{4.69\times 10^{5}\text{ N}}$, in the direction the ship was originally traveling.

18. *A 0.450-kg hammer is moving horizontally at 7.00 m/s when it strikes a nail and comes to rest after driving the nail 1.00 cm into a board. (a) Calculate the duration of the impact. (b) What was the average force exerted on the nail?*

Solution

(a) $\Delta x = \frac{1}{2}(v + v_0)\Delta t \Rightarrow \text{Since } v = 0 \text{ m/s, } \Delta t = \frac{2\Delta x}{v} = \frac{2 \times 0.0100 \text{ m}}{7.00 \text{ m/s}} = \underline{2.86 \times 10^{-3} \text{ s}}.$

(b) $\text{net } F = \frac{\Delta p}{\Delta t} = mv_0 \times \frac{v_0}{2\Delta x} = \frac{mv_0^2}{2\Delta x} = \frac{(0.450 \text{ kg})(7.00 \text{ m/s})^2}{2 \times 0.0100 \text{ m}} = \underline{1.10 \times 10^3 \text{ N}}.$

23. ***Professional Application*** *Train cars are coupled together by being bumped into one another. Suppose two loaded train cars are moving toward one another, the first having a mass of 150,000 kg and a velocity of 0.300 m/s, and the second having a mass of 110,000 kg and a velocity of* -0.120 m/s*. (The minus indicates direction of motion.) What is their final velocity?*

Solution

$$m_1 v_1 + m_2 v_2 = (m_1 + m_2)v',$$

$$v' = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2} = \frac{(150{,}000 \text{ kg})(0.300 \text{ m/s}) + (110{,}000 \text{ kg})(-0.120 \text{ m/s})}{150{,}000 \text{ kg} + 110{,}000 \text{ kg}} = \underline{0.122 \text{ m/s}}$$

24. *Suppose a clay model of a koala bear has a mass of 0.200 kg and slides on ice at a speed of 0.750 m/s. It runs into another clay model, which is initially motionless and has a mass of 0.350 kg. Both being soft clay, they naturally stick together. What is their final velocity?*

Solution This is a perfectly inelastic collision, therefore:

$$m_1 v_1 + m_2 v_2 = (0.200 \text{ kg})(0.750 \text{ m/s}) + 0 = (0.550 \text{ kg})v_\text{f} \text{ so } v_\text{f} = \underline{0.272 \text{ m/s}}$$

32. *During an ice show, a 60.0-kg skater leaps into the air and is caught by an initially stationary 75.0-kg skater. (a) What is their final velocity assuming negligible friction and that the 60.0-kg skater's original horizontal velocity is 4.00 m/s? (b) How much kinetic energy is lost?*

Solution

(a) $m_1 v_1 = (m_1 + m_2)v', \; v' = \frac{m_1 v_1}{m_1 + m_2} = \frac{(60.0 \text{ kg})(4.00 \text{ m/s})}{60.0 \text{ kg} + 75.0 \text{ kg}} = 1.778 \text{ m/s} = \underline{1.78 \text{ m/s}}$

$$\Delta \text{KE} = \frac{1}{2}(m_1 + m_2)v'^2 - \frac{1}{2}m_1 v_1^2$$

$$= 0.5(60.0 \text{ kg} + 75.0 \text{ kg})(1.778 \text{ m/s})^2 - 0.5(60.0 \text{ kg})(4.00 \text{ m/s})^2$$

(b) $= -266.613 \text{ J} = \underline{-267 \text{ J}}$

36. ***Professional Application*** *A 30,000-kg freight car is coasting at 0.850 m/s with negligible friction under a hopper that dumps 110,000 kg of scrap metal into it. (a) What is the final velocity of the loaded freight car? (b) How much kinetic energy is lost?*

Solution

(a) $$m_1 v_1 = m'_1\, v'_1\, ;\, v'_1 = \frac{-m_1 v_1}{m'_1} = \frac{(30{,}000\text{ kg})(0.850\text{ m/s})}{30{,}000\text{ kg} + 110{,}000\text{ kg}} = \underline{0.182\text{ m/s}}$$

(b) $$\Delta\text{KE} = \frac{1}{2} m'_1\, v'^2_1 + \frac{1}{2} m_1 v'^2_1$$
$$= 0.5(140{,}000\text{ kg})(0.182\text{ m/s})^2 - 0.5(30{,}000\text{ kg})(0.850\text{ m/s})^2 \cong \underline{8.52 \times 10^3\text{ J}}$$

37. ***Professional Application*** *Space probes may be separated from their launchers by exploding bolts. (They bolt away from one another.) Suppose a 4800-kg satellite uses this method to separate from the 1500-kg remains of its launcher, and that 5000 J of kinetic energy is supplied to the two parts. What are their subsequent velocities using the frame of reference in which they were at rest before separation?*

Solution

By conservation of momentum: $m_1 v_1 + m_2 v_2 = 0 \Rightarrow v_2 = \dfrac{-m_1 v_1}{m_2}$

By conservation of energy: $\dfrac{1}{2} m_1 v_1^2 + \dfrac{1}{2} m_2 v_2^2 = \Delta\text{KE}$, so that $m_1 v_1^2 + m_2 v_2^2 = 2\Delta\text{KE}$ or

$$m_1 v_1^2 + m_2 \frac{m_1^2 v_1^2}{m_2^2} = 2\Delta\text{KE}$$

$$v_1 = \left(\frac{2\Delta\text{KE}}{m_1 + (m_1^2/m_2)}\right)^{1/2} = \left[\frac{2(5000\text{ J})}{4800\text{ kg} + [(4800\text{ kg})^2/1500\text{ kg}]}\right]^{1/2} = 0.7043\text{ m/s} = \underline{0.704\text{ m/s}}$$

(assuming three significant figure accuracy)

$$v_2 = \frac{-m_1 v_1}{m_2} = \frac{-(4800\text{ kg})(0.7043\text{ m/s})}{1500\text{ kg}} = \underline{-2.25\text{ m/s}}$$