CONSERVATION OF MOMENTUM KEY

Instructions: *Show your work completely in your journal when answering the following questions.*

1. A billiard ball (mass = 0.15 kg) is moving at 1.0 $^{m}/_{s}$. It rebounds from a side cushion with the same speed.
    a. What was the ball's change in momentum? *(Note: Be sure to designate which direction is "positive" and "negative.")*

    $$\Delta p = m \cdot \Delta v = m(v_2 - v_1) = (0.15\text{ kg})(-1.0\ ^{\text{m}}/_{\text{s}} - 1.0\ ^{\text{m}}/_{\text{s}})$$

    $$\boxed{\boldsymbol{\Delta p = 0.30\ ^{\text{kg}\cdot\text{m}}/_{\text{s}}}}$$

    b. How is momentum conserved in this collision?

    The momentum is conserved in the system. Since the ball collides with the side cushion, when we consider the cushion we will see momentum is conserved.

2. A 4.0 kg mass is moving at 3.0 $^{m}/_{s}$ toward the right and a 6.0 kg mass is moving at 2.0 $^{m}/_{s}$ to the left on a horizontal frictionless table. If the two masses collide and remain together after the collision, what is their final momentum?

    $$p_{before} = p_{after} = m_1 v_1 + m_2 v_2 = (4.0\text{ kg})(3.0\ ^{\text{m}}/_{\text{s}}) + (6.0\text{ kg})(-2.0\ ^{\text{m}}/_{\text{s}}) = 0\text{ N}\cdot\text{s}$$

    $$\boxed{\boldsymbol{p_{after} = 0\text{ N}\cdot\text{s}}}$$

3. A toy train car with a mass of 200. g and a velocity of 0.80 $^{m}/_{s}$ collides with a second car that is at rest and has equal mass. The two cars couple together.
    a. Assuming no friction, what is the velocity of the 2 cars after collision?

    $$p_{before} = p_{after} \rightsquigarrow m_1 v_1 + m_2 v_2 = (m_1 + m_2)\, v'$$
    $$(0.200\text{ kg})(0.80\ ^{\text{m}}/_{\text{s}}) + (0.200\text{ kg})(0\ ^{\text{m}}/_{\text{s}}) = (0.200\text{ kg} + 0.200\text{ kg})\, v'$$

    $$\boxed{\boldsymbol{v' = 0.40\ ^{\text{m}}/_{\text{s}}}}$$

    b. What is the momentum of the 2-car system before and after the collision?

    $$p_{before} = m_1 v_1 + m_2 v_2 = (0.200\text{ kg})(0.80\ ^{\text{m}}/_{\text{s}}) + (0.200\text{ kg})(0\ ^{\text{m}}/_{\text{s}}) = 0.16\text{ N}\cdot\text{s}$$

    $$\boxed{\boldsymbol{p_{before} = p_{after} = 0.16\text{ N}\cdot\text{s}}}$$

    c. The two moving cars above collide with a 3rd car, mass of 150 g (at rest), and couple together. What is the resulting velocity of the 3 cars?

    $$p_{before} = p_{after} \rightsquigarrow (m_1 + m_2)v_{1+2} + m_3 v_3 = (m_1 + m_2 + m_3)\, v'$$
    $$(0.200\text{ kg} + 0.200\text{ kg})(0.40\ ^{\text{m}}/_{\text{s}}) + (0.150\text{ kg})(0\ ^{\text{m}}/_{\text{s}}) = (0.200\text{ kg} + 0.200\text{ kg} + 0.150\text{ kg})\, v'$$

    $$\boxed{\boldsymbol{v' = 0.29\ ^{\text{m}}/_{\text{s}}}}$$

    d. What is the momentum before and after the collision?

$$\boxed{\boldsymbol{p_{before} = p_{after} = 0.16\ \mathrm{N \cdot s}}}$$

4. A small child on a sled (total mass 45 kg) is pulled so that the sled goes from rest to 4.5 m/s.
   a. If the force applied is 40. N, what is the total distance covered during the impulse?

$$F_{NET} = ma \rightsquigarrow a = \frac{F_{NET}}{m} = \frac{40\ \mathrm{N}}{45\ \mathrm{kg}} = 0.89\ ^{\mathrm{m}}/_{\mathrm{s}^2}$$

$$v_2^{\,2} = v_1^{\,2} + 2ad \rightsquigarrow d = \frac{v_2^{\,2} - v_1^{\,2}}{2a} = \frac{(4.5\ ^{\mathrm{m}}/_{\mathrm{s}})^2 - (0\ ^{\mathrm{m}}/_{\mathrm{s}})^2}{2\left(0.89\ ^{\mathrm{m}}/_{\mathrm{s}^2}\right)}$$

$$\boxed{\boldsymbol{d = 11\ \mathrm{m}}}$$

   b. What is the change in momentum of the child and sled? Is momentum conserved? Explain…

$$I = \Delta p = m \cdot \Delta v = m(v_2 - v_1) = (45\ \mathrm{kg})(4.5\ ^{\mathrm{m}}/_{\mathrm{s}} - 0\ ^{\mathrm{m}}/_{\mathrm{s}})$$

$$\boxed{\boldsymbol{I = 203\ \mathrm{N \cdot s}}}$$

   When we only look at the child on the sled, there is a change in momentum. However, momentum is conserved for the whole system.

5. A 1200 kg railroad car travels alone on a level frictionless track with a constant speed of 18 $^{\mathrm{m}}/_{\mathrm{s}}$. A 5750 kg additional load (initially at rest) is dropped onto the car. What will the cars speed be after the additional cargo is added?

$$p_{before} = p_{after} \rightsquigarrow m_1 v_1 + m_2 v_2 = (m_1 + m_2)\, v\,'$$

$$(1200\ \mathrm{kg})(18\ ^{\mathrm{m}}/_{\mathrm{s}}) + (5750\ \mathrm{kg})(0\ ^{\mathrm{m}}/_{\mathrm{s}}) = (1200\ \mathrm{kg} + 5750\ \mathrm{kg})\, v\,'$$

$$\boxed{\boldsymbol{v\,' = 3.1\ ^{\mathrm{m}}/_{\mathrm{s}}}}$$

6. A 9500 kg boxcar traveling at 16 $^{\mathrm{m}}/_{\mathrm{s}}$ strikes a second car at rest. The two stick together and move off with a speed of 6.0 $^{\mathrm{m}}/_{\mathrm{s}}$. What is the mass of the second car?

$$p_{before} = p_{after} \rightsquigarrow m_1 v_1 + m_2 v_2 = (m_1 + m_2)\, v\,'$$

$$(9500\ \mathrm{kg})(16\ ^{\mathrm{m}}/_{\mathrm{s}}) + \left(0\ ^{\mathrm{kg \cdot m}}/_{\mathrm{s}}\right) = (9500\ \mathrm{kg} + m_2)\ (6.0\ ^{\mathrm{m}}/_{\mathrm{s}})$$

$$\boxed{\boldsymbol{m_2 = 15{,}833\ \mathrm{kg}}}$$