Conceptual Problems

10. Can objects in a system have momentum while the momentum of the system is zero? Explain your answer.

Solution
Yes, the momentum of a system can be zero even if the objects composing the system have nonzero momentum if the vector sum of the momentum of these objects sums to zero (i.e., their momenta cancel out).

14. Describe a system for which momentum is conserved but mechanical energy is not. Now the reverse: Describe a system for which kinetic energy is conserved but momentum is not.

Solution
A system in which momentum is conserved but not mechanical energy could be two balls of putty of the same mass and opposite initial velocities that collide and stick together. A system in which momentum is not conserved does not exist because, a change in momentum requires a net external force but, by definition, such a force would come from outside the system and so is not part of the system. Note that mechanical energy is conserved in closed systems in which all collisions are elastic.

15. Momentum for a system can be conserved in one direction while not being conserved in another. What is the angle between the directions? Give an example.

Solution
The angle between the directions must be 90°. Any system that has zero net external force in one direction and nonzero net external force in a perpendicular direction will satisfy these conditions.

16. Suppose a fireworks shell explodes, breaking into three large pieces for which air resistance is negligible. How does the explosion affect the motion of the center of mass? How would it be affected if the pieces experienced significantly more air resistance than the intact shell?

Solution
Neglecting air resistance, which is an external force, the center of mass of the shell after the explosion continues to move in the same parabolic trajectory due to gravity as it did before the explosion. If we consider air resistance to be significant, then the motion of the center of mass will drop below the parabolic trajectory.

Problems

20. A car of mass 2000 kg is moving with a constant velocity of 10 m/s due east. What is the momentum of the car?

Solution

$20{,}000\ \text{kg}\cdot\text{m/s}$ due east

22. If a rainstorm drops 1 cm of rain over an area of 10 km^2 in the period of 1 hour, what is the momentum of the rain that falls in one second? Assume the terminal velocity of a raindrop is 10 m/s.

Solution

$2.8\times10^{6}\ \text{kg}\cdot\text{m/s}$

30. 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. Assume constant acceleration of the hammer-nail pair.

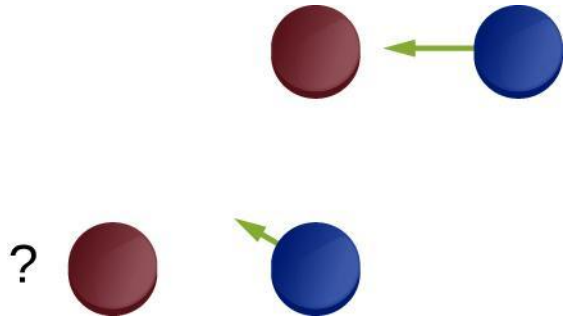
a. Calculate the duration of the impact.

b. What was the average force exerted on the nail?

Solution

a. $2.86\times10^{-3}\ \text{s}$; b. $1.10\times10^{3}\ \text{N}$

36. Two identical pucks collide elastically on an air hockey table. Puck 1 was originally at rest; puck 2 has an incoming speed of 6.00 m/s and scatters at an angle of 30° with respect to its incoming direction. What is the velocity (magnitude and direction) of puck 1 after the collision?



Solution

$\vec{\mathbf{v}}_{1,\mathrm{f}} = -\left(3.0\ \mathrm{m/s}\right)\hat{\mathbf{i}}, \quad \theta = -60°$

42. A 2000-kg railway freight car coasts at 4.4 m/s underneath a grain terminal, which dumps grain directly down into the freight car. If the speed of the loaded freight car must not go below 3.0 m/s, what is the maximum mass of grain that it can accept?

Solution

$9.3\times10^{2}\ \mathrm{kg}$

44. Ernest Rutherford (the first New Zealander to be awarded the Nobel Prize in Chemistry) demonstrated that nuclei were very small and dense by scattering helium-4 nuclei from gold-197 nuclei. The energy of the incoming helium nucleus was $8.00\times10^{-13}\ \mathrm{J}$, and the masses of the helium and gold nuclei were $6.68\times10^{-27}\ \mathrm{kg}$ and $3.29\times10^{-25}\ \mathrm{kg}$, respectively (note that their mass ratio is 4 to 197).

a. If a helium nucleus scatters to an angle of $120°$ during an elastic collision with a gold nucleus, calculate the helium nucleus's final speed and the final velocity (magnitude and direction) of the gold nucleus.

b. What is the final kinetic energy of the helium nucleus?

c.

Solution

(a) $v_{\mathrm{Au}} = 5.4\times10^{5}\ \mathrm{m/s}, \quad \theta_{\mathrm{Au}} = -29°$, (b) $7.5\times10^{-13}\ \mathrm{J}$

60. A family is skating. The father (75 kg) skates at 8.2 m/s and collides and sticks to the mother (50 kg), who was initially moving at 3.3 m/s and at 45° with respect to the father's velocity. The pair then collides with their daughter (30 kg), who was stationary, and the three slide off together. What is their final velocity?

Solution

4.6 m/s at 9.1° with respect to the father's initial velocity

68. Find the center of mass of a one-meter long rod, made of 50 cm of iron (density $8\frac{\text{g}}{\text{cm}^3}$) and 50 cm of aluminum (density $2.7\frac{\text{g}}{\text{cm}^3}$).

Solution
12.6 cm from the center of the iron rod towards the aluminum rod

80. How much fuel would be needed for a 1000-kg rocket (this is its mass with no fuel) to take off from Earth and reach 1000 m/s in 30 s? The exhaust speed is 1000 m/s.

Solution
$2.65\times10^3\ \text{kg}$

95. A load of gravel is dumped straight down into a 30 000-kg freight car coasting at 2.2 m/s on a straight section of a railroad. If the freight car's speed after receiving the gravel is 1.5 m/s, what mass of gravel did it receive?

Solution
$14\times10^3\ \text{kg}$

103. Three skydivers are plummeting earthward. They are initially holding onto each other, but then push apart. Two skydivers of mass 70 and 80 kg gain horizontal velocities of 1.2 m/s east and 1.4 m/s southeast, respectively. What is the horizontal velocity of the third skydiver, whose mass is 55 kg?

Solution
3.3 m/s, 64° west of north

105. A billiard ball traveling at $(2.2\ \text{m/s})\hat{\mathbf{i}}-(0.4\ \text{m/s})\hat{\mathbf{j}}$ collides with a wall that is aligned in the $\hat{\mathbf{j}}$ direction. Assuming the collision is elastic, what is the final velocity of the ball?

Solution
$-(2.2\ \text{m/s})\hat{\mathbf{i}}-(0.4\ \text{m/s})\hat{\mathbf{j}}$

109. Where is the center of mass of a semicircular wire of radius *R* that is centered on the origin, begins and ends on the *x* axis, and lies in the *x,y* plane?

Solution
$(0,2R/\pi)$