AP Physics-B **Momentum and its Conservation**

Newton originally wrote for the second law of motion, "The change of motion is proportional to the motive force impressed, and is made in the direction of the right line in which that force is impressed." Notice there is no mention of mass or acceleration but change in motion. What Newton called motion we now call *MOMENTUM*.

The quantity known as momentum is one of the cornerstones of physics. It is a concept that explains much of the behavior of matter. Rene Descartes first introduced the idea of momentum in 1644. Newton included this concept in his laws of motion.

If the universe is to go on forever, then the stuff of which it is made cannot disappear. This idea, that the total amount of material in the universe does not change, is really a very old idea. The Roman poet Lucretius restated (in the first century B.C.) a belief held in Greece as early as the fifth century B.C.: the amount of matter in the universe is constant. Years before Newton was born, the conservation of mass was accepted scientific principle.

Looking at moving things in the world around us easily leads to the conclusion that everything set in motion eventually stops -- that every clock, every machine -- eventually runs down. It would appear that the amount of motion in the universe is decreasing and that the universe, like any machine, must be running down. To many philosophers of the 1600's, the idea of a universe that was running down was incompatible with the idea of the perfection of God; surely He would not construct such an imperfect mechanism. It was felt that some definition of "motion" could be found which would permit the statement that "the quantity of motion in the universe is constant." It has been shown experimentally that the momentum of a closed system is conserved. The law of conservation of momentum is equal in importance to the law of conservation of energy, which you will study later.

MOMENTUM (p) of a particle is a dynamic quantity defined as the product of the mass and the velocity of a particle. Only an external force can change the momentum of a body. The change in momentum caused by an external force depends upon the amount of force and the time the force acts. The product of the force and the time the force acts is called the **IMPULSE** (J). The impulse produces a change in momentum. Both impulse and momentum are vector quantities.

Performance Objectives: Upon completion of the readings and activities in this unit and when asked to response either orally of on a written test, you will:

- ✓ Define momentum and impulse. Know that impulse and momentum are vector quantities.
- ✓ Recognize the universality of momentum. Be able to calculate changes in momentum.
- ✓ Show an understanding of the relationship between the third law of motion and momentum changes by solving problems and explaining situations.
- ✓ State the law of conservation of momentum. Recognize its implications. Apply the law to the solution of problems.
- ✓ Explain the general nature of the law of conservation of momentum. Apply vectors to the solution of momentum problems.

Textbook Reference: Hecht Physics (Algebra/Trig): Chapter 7

"I have concluded that this question of impulsive forces is very obscure, and I think that, up to the present, none of those who have treated this subject have been able to clear up its dark corners which lie almost beyond the reach of human imagination."

--Galileo Galilei

1.) Compute the momentum of a golf ball that has a mass of 60.0 g and is moving with a velocity of 70.0 m/s.
4.2 kg·m/s (odd looking units huh?)

2.) A force of 50.0 N is applied to a hockey puck for 2.0 seconds. Calculate the magnitude of the impulse.
100 N·s

3.) Assume that the puck in problem 2 has a mass of 0.50 kg and is at rest before the impulse acts upon it. With what speed does it move across the ice after a 2.0 second period? (neglect friction) *200.0 m/s*

4.) A force of 6.0 N acts on an object for 10.0 seconds. The mass of the object is 3.0 kg. A.) What is the object's change in momentum? B.) What is its change in velocity? *60 N·s* *20 m/s*

5.) In terms of impulse and momentum, why are padded dashboards safer in automobiles?

6.) Why is a punch more forceful with a bare fist then with a boxing glove?

7.) You push a body with a force of 3.0 N for 0.50 s. What impulse do you give the body? *1.5 N·s*

8.) How great is the impulse that gives an 8.00 kg mass a change in velocity of 4.00 m/s? *32 N·s*

9.) A 3.0 kg object has been accelerated by a constant force of 12 N from 10.0 m/s to 18 m/s.
A.) What impulse was applied to the object? B.) How long was the force acting? *24 N·s* *2 sec*

10.) A constant force applied to a 2.0 kg object at rest moves it 4.0 m in 2.0 seconds. What impulse was applied?
8 N·s

11.) A railroad freight car with a mass of 5.0×10^4 kg is rolling along a level track at 0.30 m/s. A rope trails behind it. A.) A reasonable estimate of the largest forces you could apply to stop the car by pulling on the rope is 250 N. How long would it take you to bring the car to rest? B.) Ten meters from the point where you start pulling, another car is standing. Will there be a crash? *60 s*

12.) Suppose you throw a ball against a wall and catch it on the rebound. How many impulses were applied to the ball? Which impulse was the greatest?

13.) Would a head-on collision between two cars be more damaging to the occupants if the cars stick together or if the cars rebound upon impact?

The LAW OF CONSERVATION OF MOMENTUM states that the total momentum of an isolated system cannot change. In a collision, one object gains the momentum lost by the other.

Total Momentum Before Collision = Total Momentum After Collision

14.) When an apple falls to the ground and strikes the earth without rebound, what becomes of the momentum of the apple?

15.) Is it possible for a rocket to attain a speed greater than the velocity with which the exhaust gases leave it? Explain!

16.) An open freight car is coasting along on a smooth track when rain starts to fall thereby increasing the mass of the car. Does the velocity of the car remain constant (no friction)? Explain!

17.) Discuss the advisability of attempting to jump from a rowboat to a dock that seems just within jumping distance.

18.) If you throw a ball horizontally while standing on roller skates, you will roll backward with a momentum that matches that of the ball. Will you roll backward if you go through the motions of throwing the ball but instead hold onto it? Explain!

19.) When traveling in your car at highway speed, the momentum of a bug suddenly changes as it splatters into you windshield. Compared to the change of momentum of the bug, by how much does the momentum of you car change?

20.) Would you care to fire a gun that has a bullet ten times as massive as the gun? Explain!

21.) Suppose there are three astronauts outside a space ship in space, and two of them decide to play catch with the third one. All the astronauts weigh the same on earth and are equally strong. The first astronaut throws the second one toward the third one and the game begins. Describe the motion of the astronauts as the game proceeds. How long with the game last?

22.) A plastic ball of mass 200.0 g moves with a velocity of 30.0 cm/s. This plastic ball collides with a second plastic ball of mass 100.0 g that is moving along the same line with a velocity of 10.0 cm/s. After the collision, the velocity of the 100.0 g mass is 26 cm/s along the same line. What is the velocity of the 200.0 g mass after the collision? *22 cm/s along the same line*

23.) A ball of mass 10.0 g moving with a velocity of 20.0 cm/s collides with a second ball of mass 20.0 g moving along the same line with a velocity of 10 cm/s After the collision, the first ball is still moving in its original direction, but its speed is now 8 cm/s. Determine the velocity of the second ball after the collision.
16 cm/s in its original direction

24.) A puck of mass 3.0 kg, moving at 2.0 m/s eastward, strikes head-on a puck of mass 1.0 kg that is moving at 2.0 m/s westward. The pucks stick together after impact. What is the velocity of the combined mass after impact? *1.0 m/s east*

25.) A bullet of mass 50.0 g strikes a wooden block of mass 5.0 kg. The bullet becomes lodged in the block. The block with the bullet in it then flies off at 10.0 m/s. What was the original velocity of the bullet? *1010 m/s*

26.) A 100.0 g ball traveling horizontally in a straight groove at 200 cm/s strikes a 400.0 g ball that was originally at rest. After the collision, the first ball rebounds at 120 cm/s, while the other is sent forward. Calculate the velocity of the second ball. *80.0 cm/s*

27.) A 40 kg projectile leaves a 2000.0 kg launcher with a velocity of 800.0 m/s forward. What is the recoil velocity of the launcher? *16 m/s in the opposite direction*

28.) A proton (mass = 1.67×10^{-27} kg) with a speed of 1.00×10^{7} m/s collides with a motionless helium nucleus, and the proton bounces back with a speed of 6.00×10^{6} m/s. The helium nucleus moves forward with a speed of 4.00×10^{6} m/s after the bombardment. A.) Can you compute the mass of the helium nucleus? If so, what is it? B.) Can you compute the force that acted during the collision? If so, what is it? C.) If you answered "no" to either (A) or (B), discuss why you gave this answer. *6.67×10^{-27} kg*

COLLISIONS IN TWO DIMENSIONS: Don't forget your vector stuff!

29.) Ball A of mass 2.0 kg is moving at a velocity of 5.0 m/s. Ball A collides with a second stationary ball B, also of mass 2.0 kg. After the collision, ball A moves off in the direction 30° to the left of its original direction. Ball B moves off in the direction 60° to the right of ball A's original direction.
A.) Draw a vector diagram to find the momentum of ball A and of ball B after the collision. B.) What is the speed of each ball after the collision? *4.33 m/s 2.5 m/s*

30.) Abject A of mass 6.0 kg moves at a speed of 3.0 m/s. It collides with object B also of mass 6.0 kg. After the collision, object A moves off in the direction 50° to the left of its original direction. Object B moves off in a direction 40° to the right of object A's original direction. A.) Draw a vector diagram to determine the momentum of object A and of object B. B.) What is the speed of each object after the collision? *11.57 kg•m/s 1.93 m/s 13.79 kg•m/s 2.3 m/s*

31.) A star of mass 2.0×10^{30} kg moving with a velocity of 2.0×10^{4} m/s collides with a second star of mass 5.0×10^{30} kg moving with a velocity of 3.0×10^{4} m/s in a direction at right angles to the first star. If the two stars join together, what is their common velocity? *2.2×10^{4} m/s*