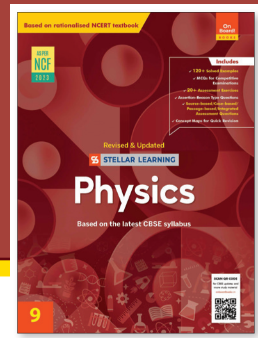
Based on the latest CBSE syllabus 2025–26

— SUPPLEMENT —

STELLAR LEARNING Physics Class 9



READING MATERIAL

Conservation of Momentum

The law of conservation of momentum states that if the net external force acting on a system is zero, the total momentum of the system remains constant (or conserved).

Mathematically, $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$, where for a system of two masses m_1 and m_2, u_1 and u_2 are respective initial velocities and v_1 and v_2 are respective final velocities.

Study Byte

A smart way to begin solving a problem related to conservation of momentum is to identify the system within which the momentum is to be conserved.

Some examples of conservation of momentum are as follows:

- **Gun and Bullet:** Before firing, both the gun and bullet are at rest, i.e. the total momentum is zero. When the gun is fired, the bullet moves forward with a certain large velocity. So that the total momentum of the gun-bullet system remains at zero, the momentum of the gun should be equal to the momentum of the bullet, but in the opposite direction. Since the mass of the gun is much larger than that of the bullet, for the momenta of the two to be equal in magnitude, the gun moves backwards with a very small velocity. This is what causes the recoil of the gun.
- **Man and Boat:** A boat is at rest near the bank of a river, and a man is standing inside the boat. The total momentum of the man-boat system is zero. The man jumps off from the boat in the forward direction to get to the river bank. Immediately after jumping, conservation of the momentum of the system causes the boat to be pushed slightly in the backward direction.

Conservation Laws

Conservation laws – such as those of momentum, energy, angular momentum and charge – are fundamental principles in physics, established through observation and experiment. While they cannot be formally proven, they can be verified or disproven by experimental results. A single contradictory result is sufficient to disprove a law. The law of conservation of momentum, developed over 300 years ago, has consistently held true across countless experiments and everyday phenomena.

Solved Examples

1. A cart of mass 50 kg is moving on a straight track with a speed of 12 m/s. A mass of 10 kg is gently put into the cart. What will be the velocity of the cart after this?

Ans. Initial momentum of the system,
p_1 = 50 kg × 12 m/s

Final momentum of the system,
p_2 = (50 kg + 10 kg) × v m/s, where v is the velocity of the cart after the mass is placed in it.

According to the principle of conservation of momentum,

$$50 \text{ kg} \times 12 \text{ m/s} = 60 \text{ kg} \times v$$

or, v = 10 m/s

2. A pistol of mass 3 kg is used to fire a bullet of mass 25 g. If the bullet comes out from the pistol at a velocity of 45 m/s, what is the recoil velocity of the pistol?

Ans. Mass of the bullet (m_1) = 25 g = 0.025 kg

Mass of the pistol (m_2) = 3 kg

Velocity of the bullet after firing (v_1) = 45 m/s

Recoil velocity or velocity of the pistol after firing (v_2) = ?

If we consider the bullet and the pistol as one system, we can apply the law of conservation of momentum to it.

The velocity before firing of the bullet and the rifle is 0.

∴ Momentum of the system before firing

$$= m_1 \times 0 + m_2 \times 0 = 0$$

Then, by the principle of conservation of momentum, immediately after firing, the total momentum of the bullet–pistol system should remain 0.

Thus, $m_1 \times v_1 + m_2 \times v_2 = 0$

or $0.025 \text{ kg} \times 45 \text{ m/s} + 3 \text{ kg} \times v_2 = 0$

or $$v_2 = -\frac{0.025 \text{ kg} \times 45 \text{ m/s}}{3 \text{ kg}}$$

or $$v_2 = -0.375 \text{ m/s}$$

∴ The recoil velocity of the pistol is 0.375 m/s in a direction opposite to that of the motion of the bullet.

3. A cracker of mass 100 g explodes into two pieces of equal mass. Show that these two pieces fly with the same speed in mutually opposite directions.

Ans. Mass of the cracker, m = 100 g = 0.1 kg

The cracker is initially at rest. Therefore, initial velocity, u = 0 m/s

Initial momentum of the cracker,

$$p_1 = m \times u = 0.1 \text{ kg} \times 0 \text{ m/s} = 0$$

Since the cracker explodes into pieces of equal mass, the mass of each piece,

$$m' = \frac{m}{2} = 0.05 \text{ kg}$$

Let v_1 and v_2 be the velocities of the two pieces respectively.

Thus, momentum of first piece, $p'_1 = m' \times v_1$

and momentum of second piece, $p'_2 = m' \times v_2$

The final momentum of the cracker,

$$p_2 = m'v_1 + m'v_2$$

By the principle of conservation of momentum,

$$p_1 = p_2$$

or $$mu = m'v_1 + m'v_2$$

or $$0.1 \text{ kg} \times 0 \text{ m/s} = 0.05 \text{ kg} (v_1 + v_2)$$

or $$v_1 + v_2 = 0$$

or $$v_1 = -v_2$$

Therefore, the velocity of each piece is equal in magnitude and reverse in direction.

4. An object A of mass 8 kg starts moving from rest in a straight line towards another stationary object B of mass 20 kg. Object A moves at an acceleration of 0.1 m/s^2 and strikes object B 7 seconds later.

(a) What is the total momentum of the two objects before the impact?

(b) What is the total momentum of the two objects immediately after the impact?

(c) If object A sticks to object B after the impact, what is the velocity of this larger object immediately after the impact?

(d) On the other hand, if after the impact object A comes to rest and object B breaks off into two equal-sized objects, what is the velocity of these two smaller objects immediately after the impact? The two smaller objects have the same velocity in terms of magnitude and direction.

Ans. Mass of object A (m_A) = 8 kg

Mass of object B (m_B) = 20 kg

Initial velocity of object A (u_A) = 0 m/s

Acceleration of object A before impact (a)

$$= 0.1 \text{ m/s}^2$$

Duration of object A's motion before impact (t) = 7 s

Velocity of object B before the impact (v_{B_1}) = 0 m/s

We know that $v = u + at$

If v_{A_1} is A's velocity just before impact,

$$v_{A_1} = u_A + at$$

or $$v_{A_1} = 0 + (0.1 \text{ m/s}^2 \times 7 \text{ s}) = 0.7 \text{ m/s}$$

(a) Total momentum of the two objects before the impact $= m_A v_{A_1} + m_B v_{B_1}$

$$= (8 \text{ kg} \times 0.7 \text{ m/s}) + (20 \text{ kg} \times 0 \text{ m/s})$$

$$= 5.6 \text{ kg m/s}$$

(b) By the principle of conservation of momentum, the total linear momentum for the A–B system remains unchanged.

Therefore, the total momentum of the two objects after the impact = 5.6 kg m/s

(c) Object A sticks with object B after the impact resulting in a larger object of mass 28 kg (i.e. $M = m_A + m_B$)

If the velocity of this combined object is v, we have

$$M \times v = 5.6 \text{ kg m/s}$$

or $$v = \frac{5.6}{M} \text{ m/s} = \frac{5.6}{28} \text{ m/s} = 0.2 \text{ m/s}$$

(d) Object A comes to rest after the impact, i.e.

$$v_{A_2} = 0 \text{ m/s}$$

Object B breaks off into two equal-sized objects, with mass of each smaller object being

$$m = \frac{m_B}{2} = \frac{20 \text{ kg}}{2} = 10 \text{ kg}$$

Therefore, $m_A v_{A_2} + m v_{B_2} + m v_{B_2} = 5.6$ kg m/s, where v_{B_2} is the velocity of each smaller object.

This gives us (8 kg × 0 m/s) + (2 × 10 kg × v_{B_2}) = 5.6 kg m/s

or $$v_{B_2} = \frac{5.6}{20} \text{ m/s} = 0.28 \text{ m/s}$$

5. From a rifle of mass 4 kg, a bullet of mass 50 g is fired with an initial velocity of 35 m/s. Calculate the initial recoil velocity of the rifle.

Ans. Mass of the bullet (m_1) = 50 g

$$= \frac{50}{1000} \text{ kg} = 0.05 \text{ kg}$$

Mass of the rifle (m_2) = 4 kg

Velocity of the bullet (v_1) = 35 m/s

Let the recoil velocity of the gun be v_2.

Before firing, both the gun and the bullet are at rest. So,

total momentum of the system before firing = 0 ... (1)

According to the law of conservation of momentum,

$$\left[\begin{array}{c}\text{Total momentum of the} \\ \text{system before firing}\end{array}\right] = \left[\begin{array}{c}\text{Total momentum of the} \\ \text{system after firing}\end{array}\right] \quad \text{... (2)}$$

From (1) and (2), we get

0 = Total momentum of the system after firing ... (3)

or $m_1 v_1 + m_2 v_2 = 0$

or 0.05 kg × 35 m/s + 4 kg × v_2 = 0

or 4 kg × v_2 = – 0.05 kg × 35 m/s

or $$v_2 = \frac{-0.05 \text{ kg} \times 35 \text{ m/s}}{4 \text{ kg}}$$

$$v_2 = -0.4375 \text{ m/s}$$

The negative sign for v_2 indicates that the direction in which the gun would recoil is opposite to that of the bullet. Thus, the gun recoils with a velocity of 0.4375 m/s in a direction opposite to that of the bullet.

6. Two objects of masses 100 g and 200 g are moving along the same line and direction with velocities of 2 m/s and 1 m/s, respectively. They collide and after the collision, the first object moves at a velocity of 1.67 m/s. Determine the velocity of the second object.

Ans. Mass of the first object (m_1)

$$= 100 \text{ g} = \frac{100}{1000} \text{ kg} = 0.1 \text{ kg}$$

Mass of the second object (m_2)

$$= 200 \text{ g} = \frac{200}{1000} \text{ kg} = 0.2 \text{ kg}$$

Before collision

Initial velocity of the first object (u_1) = 2 m/s

Initial velocity of the second object (u_2) = 1 m/s

Momentum of the first object = $m_1 \times u_1$

= 0.1 kg × 2 m/s = 0.2 kg m/s

Momentum of the second object = $m_2 \times u_2$

= 0.2 kg × 1 m/s = 0.2 kg m/s

Total momentum before collision

= 0.2 kg m/s + 0.2 kg m/s

= 0.4 kg m/s

After collision

Final velocity of the first object (v_1) = 1.67 m/s

Final velocity of the second object (v_2) = ?

(to be calculated)

Momentum of the first object

= 0.1 kg × 1.67 m/s

= 1.67 kg m/s

Momentum of the second object = 0.2 kg × v_2

Total momentum after collision

= 1.67 kg m/s + 0.2 kg × v_2

According to the law of conservation of momentum,

$$\left[\begin{array}{c}\text{Total momentum of the} \\ \text{system before collision}\end{array}\right] = \left[\begin{array}{c}\text{Total momentum of the} \\ \text{system after collision}\end{array}\right]$$

or 0.4 kg m/s = 0.167 kg m/s + 0.2 kg × v_2

or 0.4 kg m/s – 0.167 kg m/s = 0.2 kg × v_2

or 0.233 kg m/s = 0.2 kg v_2

or $$v_2 = \frac{0.233 \text{ kg m/s}}{0.2 \text{ kg}}$$

or $$v_2 = 1.165 \text{ m/s}$$

So, the velocity of the second object after collision is 1.165 m/s.

Self-Assessment

Multiple-Choice Questions

1. The principle of conservation of momentum states that the momentum of a system

(a) cannot be changed.

(b) cannot remain constant.

(c) can be changed only if internal forces act.

(d) can be changed only if external forces act.

2. The principle of conservation of momentum is deduced from

(a) Newton's first law of motion.

(b) Newton's second law of motion.

(c) Newton's third law of motion.

(d) It is an independent law not connected to any of Newton's laws.

3. Which of these is the essential condition for the validity of the law of conservation of momentum?

(a) The system should be isolated.

(b) The system should have no more than two bodies interacting with each other.

(c) At least one of the bodies in the system should be stationary.

(d) None of these. The law is valid under all conditions.

Very Short Answer Type Question

4. When a ball is thrown upwards, its momentum first decreases and then increases. Is the principle of conservation of linear momentum violated in this process?

Short Answer Type Questions

5. A ball X of mass 1 kg travelling at 5 m/s has a head-on collision with an identical ball Y at rest. Ball X stops and ball Y moves off. Calculate the velocity of ball Y after the collision.

6. Object A of mass m_1 is moving in a certain direction at a velocity of v_1, and object B of mass m_2 is moving in the same direction with velocity v_2. Objects A and B collide and stick together, with the velocity of the combined mass being $\frac{v_1+v_2}{2}$. If v_1 is not equal to v_2, what is the relationship between m_1 and m_2?

Long Answer Type Question

7. (a) With the help of the Newton's third law of motion prove that the total momentum of two bodies is conserved during collision, provided no external force acts on them.

(b) A car A of mass 1200 kg travelling at 20 m/s collides with another car B of mass 800 kg travelling at 10 m/s in the same direction. After collision, the velocity of car A becomes 15 m/s. Calculate the velocity of car B after the collision.