

How momentum is conserved in collisions

Physics grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · Lesson

Quick answer: Momentum is the product of an object's mass and its velocity, $p = mv$, measured in kg m/s. It is a vector that points the way the object moves. In a closed system the total momentum stays constant during collisions and explosions, and a force acting for a time changes momentum by the impulse $F t$.

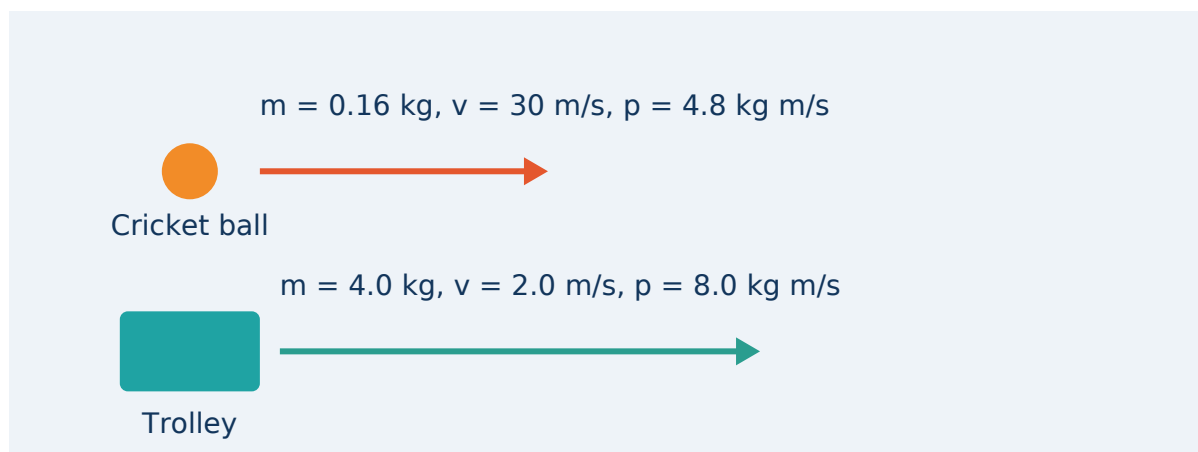
Level: Physics grades 9-10 (GCSE · IGCSE · O Level · Class 9-10) · **Curriculum:** HS-PS2-2, HS-PS2-3

What is momentum?

Some moving things are hard to stop even when they move slowly, and others are hard to stop because they move fast. Momentum measures that difficulty. It depends on both the mass of the object and its velocity.

Definition

Momentum is the product of an object's mass and its velocity. It is a vector, so it points the same way as the velocity. Its SI unit is the kilogram metre per second (kg m/s), which is the same as the newton second (N s).



Arrow length shows momentum. The slow, heavy trolley carries more momentum than the fast, light ball.

How do you calculate momentum?

Formula

$$p = m \times v$$

p = momentum (kg m/s), m = mass (kg), v = velocity (m/s).

Convert grams to kilograms first, and divide km/h by 3.6 to get m/s.

Worked example 1

Wanjiru in Nairobi watches a cricket ball of mass 0.16 kg travel at 30 m/s. Calculate its momentum.

$$p = m \times v = 0.16 \times 30 = \mathbf{4.8 \text{ kg m/s}}, \text{ in the direction the ball moves.}$$

Object	Mass (kg)	Speed (m/s)	Momentum (kg m/s)
Football in a free kick	0.43	20	8.6
Cyclist and bike	80	6.0	480
Hatchback car	1200	15	18 000
Loaded lorry	8000	10	80 000

A slow lorry has far more momentum than a fast football, because its mass is thousands of times larger.

What does conservation of momentum say?

Key law

In a closed system, where no external resultant force acts, the total momentum before an interaction equals the total momentum after it: $\mathbf{m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2}$.

During a collision the two objects push on each other with equal and opposite forces for the same time. One object gains exactly the momentum the other loses, so the total does not change. Pick one direction as positive and give momenta in the opposite direction a minus sign.

Worked example 2

Diego in Texas rolls a 2.0 kg trolley at 3.0 m/s into a 1.0 kg trolley at rest. They lock together. Calculate their common velocity.

Before: $2.0 \times 3.0 + 1.0 \times 0 = 6.0 \text{ kg m/s}$. After: $(2.0 + 1.0) \times v = 3.0 v$. So $v = 6.0 \div 3.0 = \mathbf{2.0 \text{ m/s}}$ in the original direction.



Worked example 2: total momentum is 6.0 kg m/s before and 6.0 kg m/s after.

Common mistake

Do not add speeds, and do not forget signs. Momentum is conserved, but kinetic energy is not when objects stick. In example 2 the kinetic energy falls from 9.0 J to 6.0 J, and the missing 3.0 J becomes heat and sound.

What happens in an explosion or recoil?

If two objects start at rest, the total momentum is zero. When they push apart, their momenta must cancel, so they move in opposite directions. The lighter object gets the greater speed. This explains the kick of a rifle and a swimmer pushing off the pool wall.

Worked example 3

Kofi in Accra releases a spring between a 1.5 kg trolley and a 0.5 kg trolley, both at rest. The light trolley leaves at 3.0 m/s to the right. Find the velocity of the heavy trolley.

Take right as positive. $0 = 0.5 \times 3.0 + 1.5 \times v$, so $v = -1.5 \div 1.5 = -1.0 \text{ m/s}$, which means 1.0 m/s to the left.



Worked example 3: the total momentum is zero before and zero after, so the two momenta cancel.

What is impulse and how does it keep us safe?

A force that acts for a time changes momentum. Starting from $F = ma$ and $a = (v - u) \div t$, you get $F t = m(v - u)$.

Formula

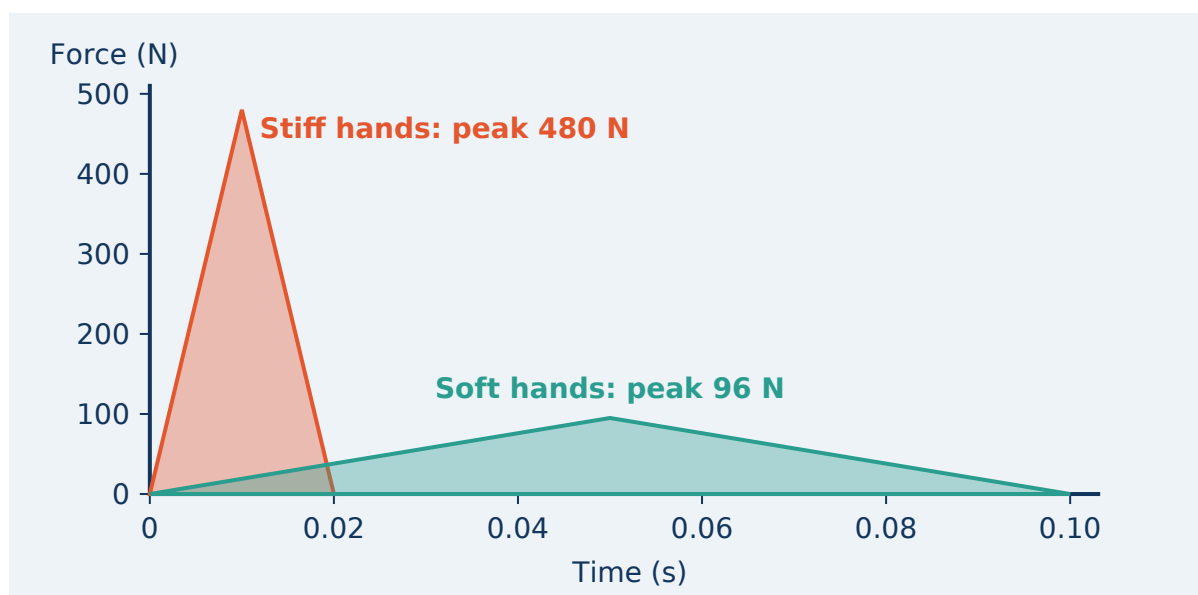
$$F t = \Delta p = m(v - u)$$

F = average force (N), t = time of contact (s), Δp = change in momentum (kg m/s), u = initial velocity and v = final velocity (m/s). The product $F t$ is called impulse.

Worked example 4

Chiamaka in Lagos catches the 0.16 kg ball moving at 30 m/s. Find the average force if her hands stop it in 0.020 s, then in 0.10 s.

$\Delta p = 0.16 \times 30 = 4.8$ kg m/s. Stiff hands: $F = 4.8 \div 0.020 = \mathbf{240 \text{ N}}$. Hands drawn back: $F = 4.8 \div 0.10 = \mathbf{48 \text{ N}}$.



Both curves enclose the same area (impulse 4.8 N s). Stretching the stopping time lowers the force.

The change in momentum is fixed, so a longer stopping time means a smaller force. Safety designs use this idea.

Safety feature	How it lowers the force
Crumple zone	The car body collapses and stretches the crash time
Airbag	Slows the head gradually and spreads the force over a large area
Seat belt	Stretches slightly so the body stops over a longer time
Cycle helmet	Foam crushes and adds time to the impact
Gym mat	Soft surface increases the landing time

Lina's tip

Before any collision problem, sketch Before and After, choose a positive direction, and write each momentum with its sign. Most lost marks come from missing minus signs.

Key points to remember

- Momentum $p = m \times v$, in kg m/s (same as N s).
- Momentum is a vector with the direction of the velocity.
- Closed system: total momentum before = total momentum after.
- Impulse $F t = \Delta p = m(v - u)$, measured in N s.
- A longer stopping time lowers the force: airbags, crumple zones and helmets use this.

How momentum is conserved in collisions: frequently asked questions

What is momentum in simple terms?

Momentum is how much motion an object has, found by multiplying its mass by its velocity. A heavy object moving slowly can have as much momentum as a light one moving fast.

Is momentum the same as force?

No. Momentum is a property of a moving object, measured in kg m/s, while force is a push or pull measured in newtons. A force acting for a time changes the momentum.

Why is momentum conserved in a collision?

The two objects exert equal and opposite forces on each other for the same time. One gains the momentum the other loses, so the total stays constant as long as no outside force acts.

Is kinetic energy conserved in collisions?

Only in elastic collisions. When objects stick together or deform, some kinetic energy becomes heat and sound, but the total momentum is still conserved.

How do airbags and crumple zones protect people?

They make the stopping time longer. Since the change in momentum is fixed, the average force $F = \Delta p \div t$ becomes smaller and causes less injury.