Chapter 4: Momentum, Impulse, and Collisions

4.1 Momentum

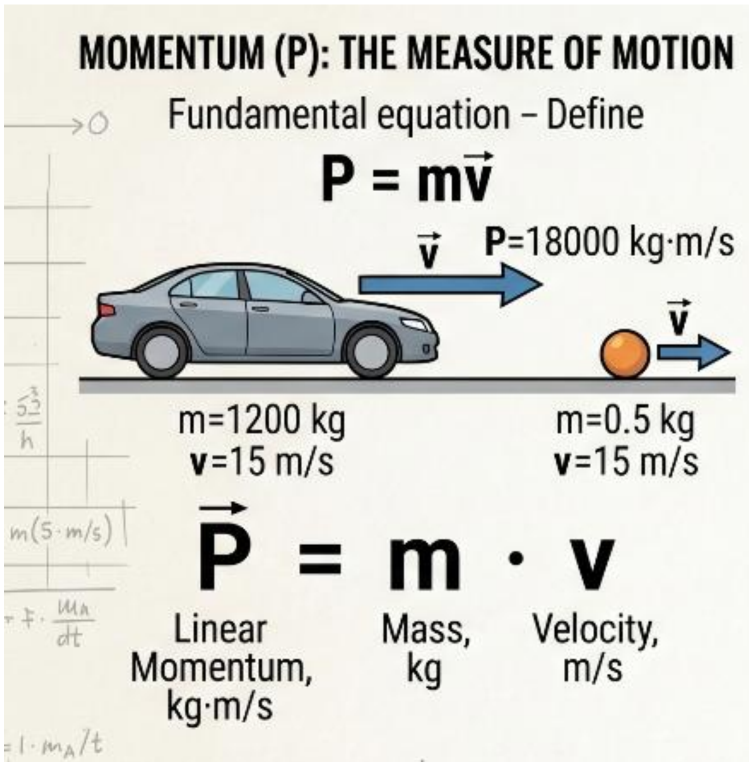

Figure 4.1: Image showing the momentum of a vehicle

Definition of Momentum

Momentum is a fundamental concept in physics that measures the amount of motion an object possesses. It depends on two key factors:

$$p = mv$$

kg·m/s),

m = mass of the object (kg),2

v = velocity of the object (m/s).

Momentum is a vector quantity, meaning it has both magnitude and direction. An object moving east at 10 m/s with momentum of $100\ kg \cdot m/s$ is different from an object moving west with the same magnitude of momentum.

Key Idea: The greater the mass and velocity of an object, the larger its momentum.

Types of Momentum

Linear Momentum

This is momentum that applies to objects moving in a straight line.

Example: A moving truck, a rolling football.

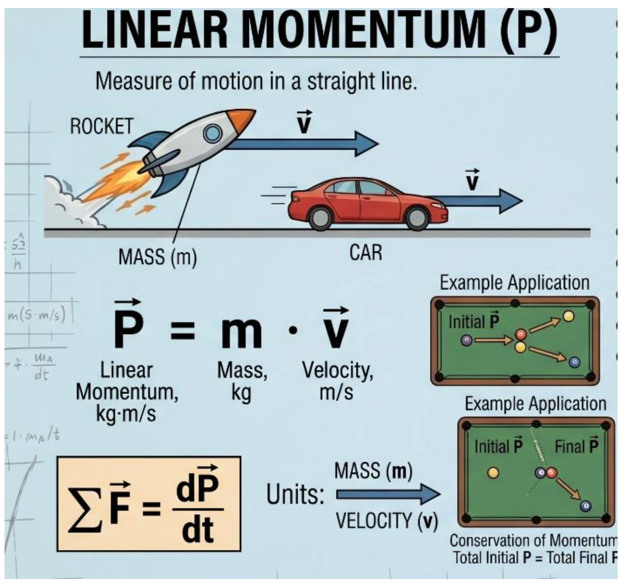

Figure 4.1: Linear momentum

Angular Momentum

Associated with rotating or spinning objects.

Defined as: $L = I\omega$ where I is the moment of inertia and ω is angular velocity.

Example: A spinning wheel, a rotating planet.

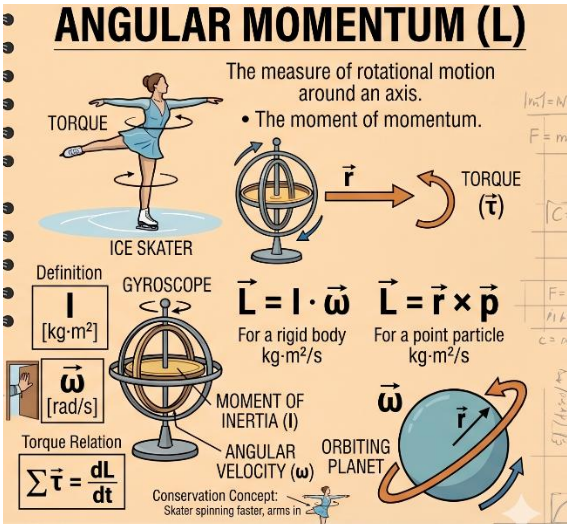

Figure 4.2: Angular momentum illustration

Examples from Everyday Life

- A heavy truck moving slowly can have more momentum than a small car moving fast because of its larger mass.
- In sports, a cricket ball hit with force carries large momentum, making it harder for the fielder to stop.
- In space travel, rockets rely on high-speed exhaust gases to gain momentum in the opposite direction.

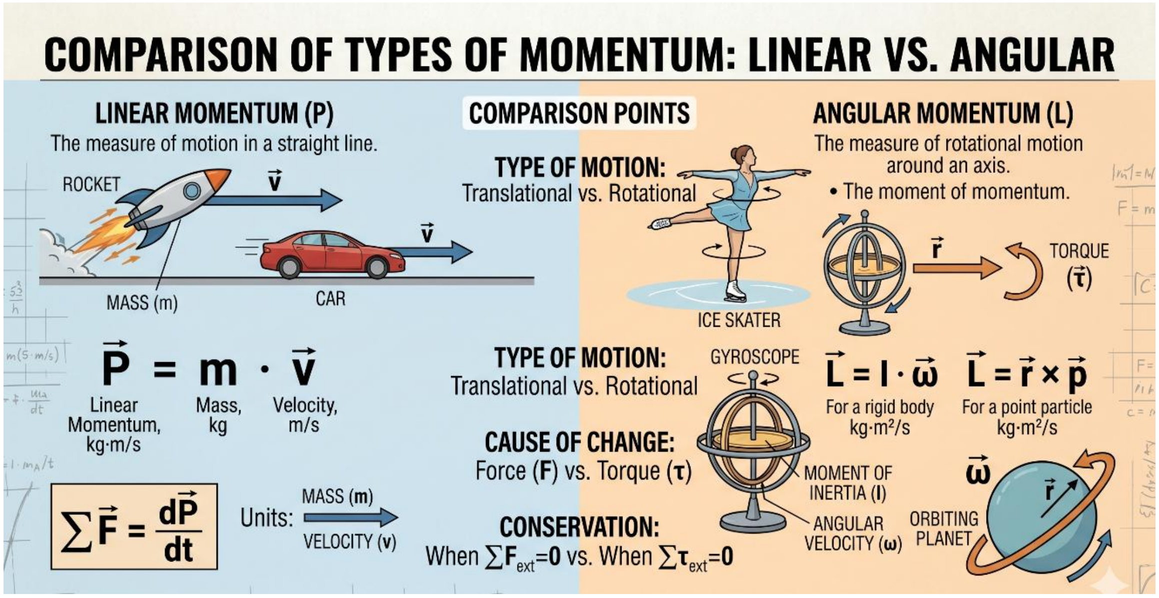

Figure 4.3: Comparison of type of Momentum

Worked Example 1: Comparing Momentum of a Truck and a Bullet

A truck of mass 2000 kg is moving at 15 m/s. A bullet of mass 0.02 kg travels at 600 m/s. Compare their momenta.

Solution:

p_{truck} = mv = 2000 × 15 = 30,000 kg·m/s

p_{bullet} = 0.02 × 600 = 12 kg·m/s

Result: Although the bullet is much faster, the truck's larger mass gives it a far greater momentum.

Worked Example 2: Football Kick

A football of mass 0.5 kg is initially at rest. A player kicks it, and it moves with a velocity of 20 m/s. Calculate the momentum of the football.

Solution:

$$p = mv = 0.5 \times 20 = 10\, kg \cdot m/s$$

Key Points to Remember

Momentum combines both mass and velocity.

It is a vector quantity thus direction matters.

Even small, fast-moving objects can have significant momentum, but usually heavy, fast objects carry the most momentum.

4.2 Impulse

Definition of Impulse

Impulse is the product of force and the time interval over which the force acts. It represents the change in momentum of an object.

$$J = F\Delta t = \Delta p$$

kg·m/s

F = force applied (N),

Δt = time of action (s),

Δp = change in momentum.

Impulse is a vector quantity and always acts in the direction of the force applied.

Units of Impulse

Impulse has the same units as momentum: $kg \cdot m/s$ (or equivalently, Newton-second, N·s).

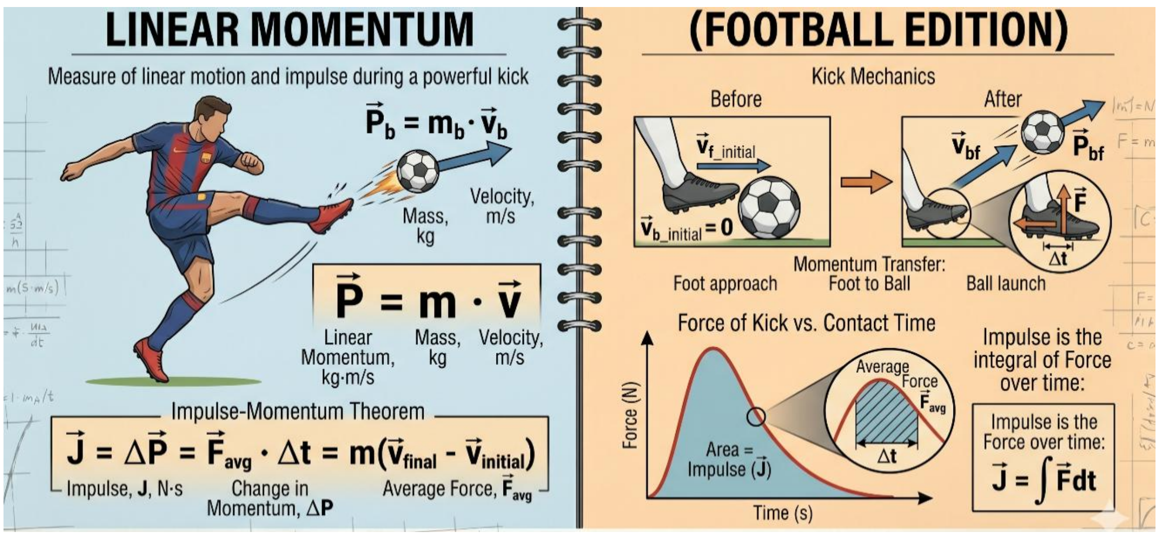

Figure 4.4: Linear Momentum and Impulse

Examples from Everyday Life

Car airbags increase the time of collision, reducing the force on passengers.

A cricket player lowers their hands while catching the ball to reduce the impact force.

Athletes use cushioned shoes to reduce impulse forces on landing.

Worked Example 1: Impulse of a Force

A force of 200 N acts on a 10 kg object for 0.5 s. Calculate the impulse and the change in momentum.

Solution:

$$J = F\Delta t = 200 \times 0.5 = 100\, N \cdot s$$

Result: The impulse is 100 N·s, meaning the object's momentum changes by 100 $kg \cdot m/s$.

Worked Example 2: Catching a Ball

A 0.15 kg ball traveling at 20 m/s is caught and stopped in 0.1 s. Determine the average force exerted on the catcher's hand.

Solution:

$$Initial\ momentum = (0.15 \times 20) = 3\, kg \cdot m/s Final\ momentum = 0\ (ball\ stopped) \Delta p = 0 - 3 = -3\, kg \cdot m/s Impulse\ J = \Delta p = -3\, N \cdot s F = J/\Delta t = -3\, /\, 0.1 = -30\, N$$

Key Points to Remember

- Impulse is the change in momentum caused by a force acting over time.
- Longer interaction time reduces the average force experienced.
- Safety devices (helmets, airbags, cushioned shoes) work by increasing collision time, reducing forces.

Exercises

1. State the Work Kinetic energy theorem both in words and mathematically.
2. An elevator cab of mass m = 500 kg is descending with speed v_i = 4.0 m/s when its supporting cable begins to tighten, allowing it to fall with constant deceleration $\vec{a} = \frac{\vec{g}}{5}$ m/s^2. Use the work-kinetic energy theorem to determine the cab's kinetic energy at the end of a 10 m fall.
3. Sphere A of mass 400 g is travelling horizontally with a speed of 6 m s^{-1} when it collides with sphere B of mass 150 g travelling in the opposite direction with a speed of 9 m s^{-1}. Sphere A comes to rest as a result of the collision. Calculate the new velocity of sphere B.

4. A boy with mass 75 kg running at $5\ m/s$ jumps on to a 20 kg trolley travelling in the same direction at $2\ m/s$. Calculate their common velocity.
5. The last part of a roller coaster's track is horizontal. The roller coaster is brought to rest using a constant braking force of 4300. N. It takes 9.00 s to bring the roller coaster to a stop from a speed of 23.0 m/s. Find the mass of the roller coaster.