Momentum

Name _____ Date _____

By the end of this topic I can…

- define momentum and relate force to the rate of change of momentum
- define impulse and use the area under a force–time graph
- state and use the principle of conservation of momentum in one dimension
- distinguish elastic from inelastic collisions

Momentum and force

Momentum

_____ is the product of _____ and _____:

$[p] =$ _____ $=$ N s

- momentum is a _____, in the same direction as the velocity
- to add momenta or find a change in momentum, keep track of _____ (take one direction as positive)

Newton's second law and momentum

For a constant force: $F = ma = \dfrac{m\Delta v}{\Delta t}$, so

_____ is the _____; the resultant force is in the direction of the change in momentum.

- this form allows for a changing mass (water from a hose, wind on a wall)
- a longer time of impact means a _____ force for the same change in momentum (crumple zones, bending your knees)
- the gradient of a momentum–time graph is the _____

Example 5.1 A ball of 120 g strikes a wall at right angle with a speed of 10 m s^{-1}. It rebounds with the same speed. If the time of impact is 25 ms, find the average force exerted on the ball.

Example 5.2 Water is pumped through a hose-pipe. A man is holding the hose-pipe horizontally and water emerges from the hose-pipe with a speed of 16 m s^{-1} at a rate of 45 kg per minute. Find the force required from this man to hold steady the hose-pipe.

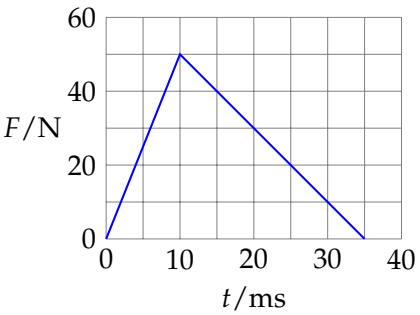
Example 5.3 A strong wind of speed 30 m s^{-1} blows against a wall of area 10 m^2 at right angles. The density of the air is 1.2 kg m^{-3}. Assume air speed reduces to zero when it hits the wall. What is the approximate force exerted by the air on the wall?

Impulse

_____ is the force multiplied by the time for which it acts, and equals the change in momentum:

- the area under a _____ graph is the _____ (the change in momentum)

Example 5.4 An object of mass 70 g is initially at rest. A force that varies with time is exerted on the object. The graph shows the how the force varies during the time of impact. What is the final velocity of the object?



Conservation of momentum

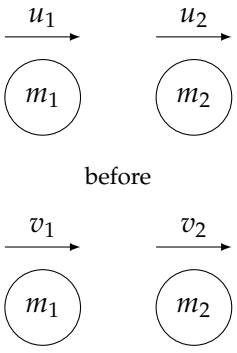
The **principle of conservation of momentum**: the total momentum of a _____ (no resultant _____ force) _____.

Why: by Newton's third law the forces two bodies exert on each other are _____ and act for the same time, so the changes in their momenta cancel.

Example 5.5 A uranium-238 nucleus (initially at rest) disintegrates, emitting an α-particle of mass 4u and leaving a thorium-234 nucleus of mass 234u. (a) Find the ratio v_α / v_{Th}. (b) Explain why they move in opposite directions.

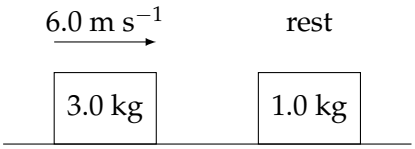
Collisions in one dimension

During a collision external forces are negligible, so total momentum is conserved. Take _____ as positive:

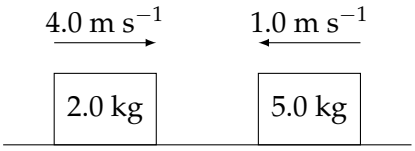


Before and after a collision.

Example 5.6 A 3.0 kg mass moving at 6.0 m s^{-1} has a head-on collision with a stationary 1.0 kg mass. The two masses stick together on impact. What is the final velocity of the two masses?



Example 5.7 A 2.0 kg mass moving at 4.0 m s^{-1} collides head on with a 5.0 kg mass moving at 1.0 m s^{-1}. After the collision, speed of the 5.0 kg mass is unchanged but its direction is reversed. What is the velocity of the 2.0 kg mass after the collision?



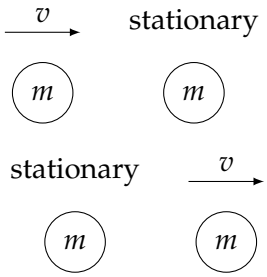
Elastic and inelastic collisions

In an **elastic collision** the total _____ is conserved. In an **inelastic collision** some kinetic energy is _____ (such as thermal energy); total _____ is conserved in both.

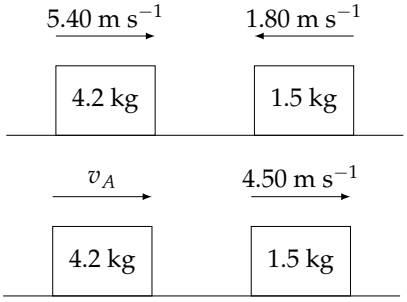
- for an elastic collision the _____ equals the _____:

- kinetic energy: $E_k = \frac{1}{2}mv^2 = \frac{p^2}{2m}$
- in a perfectly inelastic collision the bodies _____

Example 5.8 A sphere of mass m moves on a smooth horizontal surface at speed v and collides elastically and head-on with an identical sphere at rest. Find the final velocities.



Example 5.9 A 4.2 kg mass A and a 1.5 kg mass B move towards each other on a frictionless plane at 5.40 m s^{-1} and 1.80 m s^{-1}. After the collision B moves to the right at 4.50 m s^{-1}. (a) Find the velocity of A after the collision. (b) Is the collision elastic?



Example 5.10 A ball of mass $m_1 = 1.0$ kg travelling with a speed of $u = 6.0$ m s^{-1} in the x-direction strikes a stationary ball of mass $m_2 = 2.0$ kg. The direction of the balls' velocities v_1 and v_2 after the collision are shown in the diagram. Find v_1 and v_2.

Practice questions

Question 5.1 A tennis ball of mass 57 g arrives horizontally at 30 m s^{-1} and rebounds in the opposite direction at 20 m s^{-1}. The contact lasts 8.0 ms. Find the average force on the ball.

Question 5.2 A 0.50 kg trolley moving at 2.0 m s^{-1} collides with a stationary 1.5 kg trolley and they stick together. Find (a) their common velocity, (b) the kinetic energy lost.

Question 5.3 When speed cars run out of control in a racing game, why are they stopped by haystacks instead of concrete walls? When you jump from an elevated position and land on the ground, you naturally bend your knees instead of keeping your legs stiff. How does that reduce the chance of causing harmful injuries?

Question 5.4 Automobiles were manufactured to be as rigid as possible, but nowadays many cars are designed to crumple upon impact. Can you explain why?

Question 5.5 When a piece of putty falls and hits the floor without bouncing, what becomes of its momentum before impact? What becomes of its kinetic energy?