

## Topic 3 - Dynamics

### 1 Newton's first law of motion

**Newton's First law of motion:** a body continues in its state of rest or uniform motion in a straight line unless acted upon by a resultant external force

#### 1.1 Inertia

The inertia of a body is its reluctance to a change in motion

The mass  $m$  of a body is an intrinsic property which resists change in motion

#### 1.2 Equilibrium

the conditions necessary for equilibrium of a body are

- resultant force acting on body is 0
- resultant torque on the body about any axis is 0

### 2 Newton's second law of motion and Momentum

**Newton's second law of motion:** rate of change of momentum of a body is proportional to the resultant force acting on it and occurs in the direction of the force

$$F_{net} \propto \frac{d(p)}{dt}$$

#### 2.1 Momentum

Momentum of a body is defined as the product of its mass  $m$  and velocity  $v$ , ie

$$p = mv$$

#### 2.2 Newton's second law

$$\begin{aligned} F_{net} &\propto \frac{d(p)}{dt} \\ F_{net} &= k \frac{d(p)}{dt}, \text{ and since } k = 1 \text{ when quantities in S.I. units,} \\ F_{net} &= \frac{d(p)}{dt} = \frac{d(mv)}{dt} \\ &= m \frac{dv}{dt} + v \frac{dm}{dt} \end{aligned}$$

Hence

- when mass is constant,  $F_{net} = m \frac{dv}{dt}$
- when velocity is constant,  $F_{net} = v \frac{dm}{dt}$

### 3 Newton's third law of motion

**Newton's Third law of motion:** if body A exerts a force on body B, then body B exerts an equal but opposite force on A

$$|F_{by\ A\ on\ B}| = |F_{by\ B\ on\ A}|$$

$$F_{AB} = -F_{BA}$$

## 4 Impulse and momentum change

Impulse is equal to the change in momentum, defined as the product of a force  $F$  acting on an object and the time  $\Delta t$  for which the force acts

$$F = \frac{\Delta p}{\Delta t}$$

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

Impulse can be found as the area under the  $F - t$  graph

## 5 Collisions and Conservation of momentum

By Newton's Third Law, when  $A$  collides with  $B$ ,

$$F_{BA} = -F_{AB}$$

since time interval  $dt$  is the same, impulse on  $A$  is opposite to impulse on  $B$

$$\int_{t_i}^{t_f} F_{BA} dt = - \int_{t_i}^{t_f} F_{AB} dt$$

since impulse = change in momentum

$$\Delta p_a = \Delta p_b$$

$$m_A v_A + m_A u_A = -(m_B v_B - m_B u_B)$$

$$m_A u_A + m_B u_B = m_A v_A + m_B v_B$$

net initial momentum of bodies = net final momentum of bodies

**The principle of conservation of linear momentum:** when bodies in a system interact, total momentum of the system remains constant, provided no net external force acts on the system

$$\sum m_i u_i = \sum m_i v_i$$

Types of collision

- **Elastic collision** total KE conserved
- **Inelastic collision** total KE not conserved
- **Completely inelastic collision** particles have the same final velocity (particles stick together and move off together)

for elastic collision, by principle of conservation of linear momentum

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_1 v_2$$

and since that total KE remains constant

$$\frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2 = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2$$

$$m_1 u_1^2 + m_2 u_2^2 = m_1 v_1^2 + m_2 v_2^2$$

rearranging the expressions

$$\begin{aligned} m_1(u_1 - v_1) &= m_2(v_2 - u_2) \\ m_1(u_1^2 - v_1^2) &= m_2(v_2^2 - u_2^2) \end{aligned}$$

dividing the equations to remove  $m_1$  and  $m_2$

$$\begin{aligned} \frac{u_1^2 - v_1^2}{u_1 - v_1} &= \frac{u_2^2 - v_2^2}{v_2 - u_2} \\ \frac{(u_1 + v_1)(u_1 - v_1)}{u_1 - v_1} &= \frac{(v_2 + u_2)(v_2 - u_2)}{v_2 - u_2} \\ u_1 + v_1 &= v_2 + u_2 \\ u_1 - u_2 &= v_2 - v_1 \end{aligned}$$

relative speed of approach = relative speed of separation