Topic 3 – **Dynamics**

GUIDING QUESTIONS

- *How do forces affect the motion of an object?*
- *When is momentum conserved during interactions between objects?*
- *How can we analyse interactions using he principle of momentum conservation?*

Content

- Newton's laws of motion
- Linear momentum and its conservation

Learning Outcomes

Students should be able to:

(a) state and apply each of Newton's laws of motion

(b) show an understanding that mass is the property of a body which resists change in motion (inertia)

(c) describe and use the concept of weight as the force experienced by a mass in a gravitational field

(d) define and use linear momentum as the product of mass and velocity

(e) define and use impulse as the product of force and time of impact

(f) relate resultant force to the rate of change of momentum

(g) recall and solve problems using the relationship $F = ma$, appreciating that resultant force and acceleration are always in the same direction

(h) state the principle of conservation of momentum

(i) apply the principle of conservation of momentum to solve simple problems including inelastic and (perfectly) elastic interactions between two bodies in one dimension (knowledge of the concept of coefficient of restitution is not required)

(j) show an understanding that, for a (perfectly) elastic collision between two bodies, the relative speed of approach is equal to the relative speed of separation

(k) show an understanding that, whilst the momentum of a closed system is always conserved in interactions between bodies, some change in kinetic energy usually takes place.

0. Introduction


Isaac Newton

In *kinematics*, we described motion in terms of displacement, velocity and acceleration. In this chapter, we investigate what causes change in motion. The relationship between a force and the acceleration it causes was first understood by Sir Isaac Newton (1642 – 1727). The study of the relationship is called Newtonian mechanics. In this topic, the focus is on Newton's three laws of motion.

Newtonian mechanics does not apply in the following situations:

- When the speeds of the interacting bodies are very large (i.e. approaching the speed of light). In this case, Einstein's special theory of relativity replaces Newtonian mechanics.
- When the interacting bodies are on the atomic scale. In this case, quantum mechanics replaces Newtonian mechanics.

Physicists now view Newtonian mechanics as a special case of these two more comprehensive theories.

1. Newton's Laws of Motion

***LO* (a)** **state and apply each of Newton's laws of motion**

***LO* (b)** **show an understanding that mass is the property of a body which resists change in motion (inertia)**

Newton's 1st Law of Motion states that:

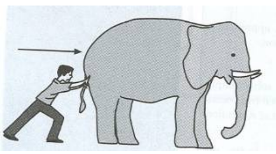
> An object at rest will remain at rest and an object in motion will remain in motion at constant velocity in the absence of an *external resultant* force.

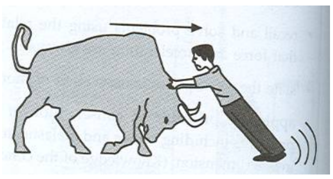
It is also known as the Law of **Inertia**.

Inertia is a measure of the reluctance of an object to change its state of rest or uniform motion in a straight line.

When a force is applied on an object, it is always easier to change the state of motion of a lighter object (smaller mass). Likewise, it will be harder to stop a heavier object (bigger mass) that is moving.

> **Mass** is a measure of body's inertia to changes in velocity. SI unit: kilogram (kg)


Hard to start moving


Hard to stop moving once it is in motion

Newton's First Law of Motion can also be used to explain the following observations:

Observation	Explanation
A passenger in a moving bus will lurch forward when the bus driver suddenly brakes.	When the bus suddenly brakes, the passenger tends to keep moving at the previous speed and lurch forward.
A passenger in a stationary bus will lurch backwards when bus driver suddenly accelerates.	When the bus suddenly accelerates, the passenger tends to stay at rest and lurch backwards.

***LO* (c)** **describe and use the concept of weight as the force experienced by a mass in the gravitational field**

The **weight** of a body is the force acting on the mass in a gravitational field. SI unit: newton (N)

weight = mass × acceleration of free fall $W = mg$

Mass is a **scalar** quantity while weight is a **vector** quantity.

Note that the mass of an object is constant all over the universe, but its weight is a force whose magnitude depends on the value of g. The direction of W is always in the direction of g. In the context of Earth, weight will always point towards the centre of the Earth.

Example 1

Determine the acceleration of free fall on the surface of Earth and Moon if a 70.0 kg mass weighs 687 N on Earth and 114 N on Moon.

	weight / N	acceleration of free fall near the planet's surface / m s^{-2}
Earth	687	
Moon	114	

***LO* (d)** **define and use linear momentum as the product of mass and velocity**

The **linear momentum** of a body is the product of the mass and its velocity. SI unit: kg m s^{-1}

momentum = mass × velocity $p = m v$

Momentum is a vector quantity. The direction of momentum is the same as the direction of the velocity.

(For the syllabus, the term *momentum* is used to mean *linear momentum,* unless specified.)

Example 2

(a) Calculate the momentum of a 100 g bullet traveling at a speed of 400 m s^{-1} to the right.

(b) Calculate the velocity required for a running person of mass 60.0 kg to have the same momentum as the bullet.

***LO* (f)** **relate resultant force to the rate of change of momentum**

Newton's 2nd Law of Motion states that:

The rate of change of momentum of a body is directly proportional to the resultant force acting on the body and occurs in the direction of the resultant force.

<u>Mathematical Interpretation of Newton's 2^nd^ Law</u>

From Newton's 2nd Law of Motion,

$$F_R \propto \frac{dp}{dt} = k\frac{dp}{dt} = k\frac{d(mv)}{dt}$$

where *k* is a constant of proportionality.

For constant mass, then

$$F_R = k\frac{d(mv)}{dt} = k \cdot m\frac{dv}{dt} = k \cdot ma$$

We make the constant *k* equals to 1 by defining the newton to be such that a resultant force of 1 N gives a mass of 1 kg an acceleration of 1 m s^{-2}:

$F_R = ma$	(only valid for constant mass)

$F_R = \dfrac{dp}{dt}$	(general form)

Note that both F_R and *a* are <u>vectors</u> – the force determines not only the <u>magnitude</u> of the acceleration, but also its <u>direction</u> – a body accelerates in the direction of the resultant force on it.

Newton's 3rd Law of Motion states that:

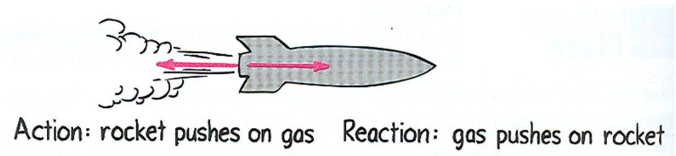
If body A exerts a force on body B, then body B exerts a force of the same type that is equal in magnitude and opposite in direction on body A.

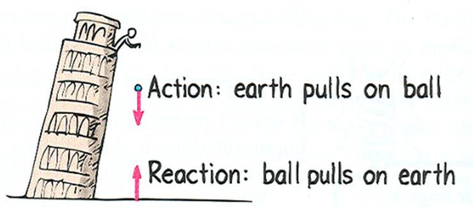
Newton's 3rd Law of Motion implies that forces occur in pairs, which fulfils the following conditions:

(a) The two forces act on <u>two different bodies.</u>
(b) The forces are <u>equal</u> in magnitude.
(c) The forces are <u>opposite</u> in direction.
(d) The forces must be of the <u>same type</u>.

These two forces are known as an **action-reaction** pair of forces.

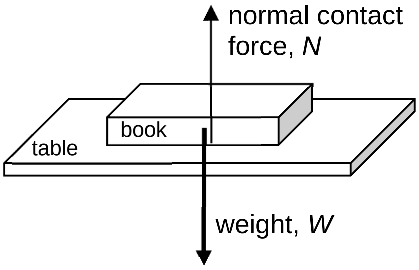
<u>Examples:</u>





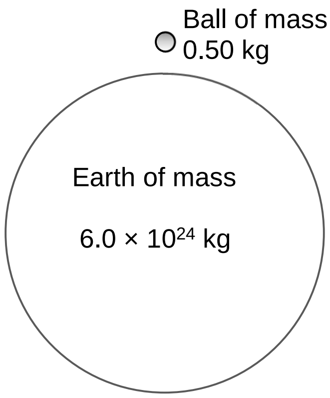
Example 3

In the free-body diagram of a book resting on a table, explain why the normal contact force, *N*, and the weight, *W*, do not form an action-reaction pair of forces even though *N* and *W* are equal in magnitude and opposite in direction.



Example 4

A 0.50 kg ball experiences an acceleration of free fall of 9.81 m s^{-2}. Find the acceleration of the Earth towards the ball (assume the ball and Earth are the only two objects in the universe).



Free-Body Diagrams

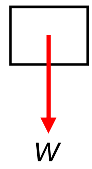
When solving problems, a free-body force diagram is vital to help you analyse the question effectively. A free-body force diagram shows **all the forces acting on the body** (in which you are interested) without showing the forces acting on the environment or other bodies. This is a useful tool used to find the resultant or net external force acting on a body and we can then set up equations to calculate the acceleration of the body using Newton's 2nd Law of Motion.

Common Forces in Free-Body Force Diagrams

weight, *W*

Gravitational force exerted by the source mass (e.g. Earth) on the body. It acts from the centre of gravity of the body and is in the same direction of the gravitational field strength, *g*.

$$W = F_G = mg$$



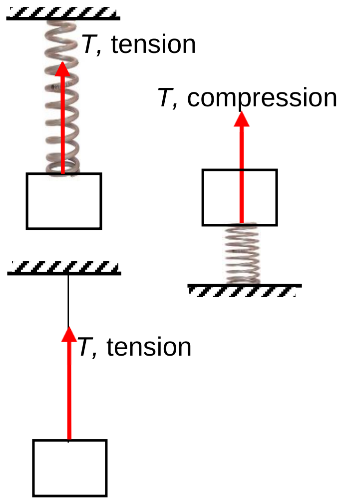
tensile and compressive forces

If the body is attached to a spring, the tension or compression of the spring will act on it. The spring can pull (tension) or push (compression).

For a spring that obeys **Hooke's Law**, the extension/compression *e* of the material is directly proportional to the tensile/compressive force acting on it.

$$T = ke$$

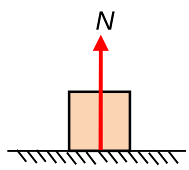
If the body is attached to a string, the tension of the string will act on it. Tension always pulls, never pushes.



normal contact force, *N*

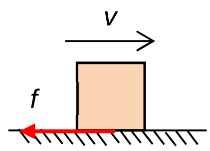
If the body is in contact with anything, there will be a normal reaction force exerted by the contact surface on the body. It acts in the direction perpendicular to the area of contact (i.e. along the normal).

(The reaction force by a hinge can act at any angle to a hinged object, so insert it at an unknown angle.)



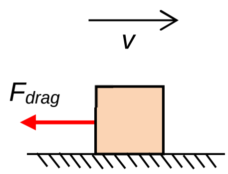
frictional force, *f*

Friction will act if the body is in contact with a rough surface, and if it is moving or has any "tendency" to move. Having a "tendency" to move means the body would move if there was no friction. Friction exerted by the surface acts parallel to the surface, in the direction opposite to the way the body moves or would tend to move.



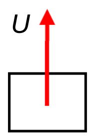
viscous force, $F_{viscous}$ (including air resistance/drag, F_{drag})

The resistance to the movement of a body through a fluid is the viscous force exerted **by** the fluid **on** the body. It acts in the direction opposite to that of the motion of the body.



upthrust, *U*

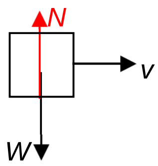
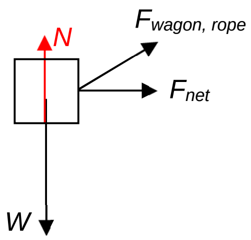
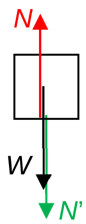
Upward force exerted on submerged objects in a fluid (liquid or gas). It acts from the centre of gravity of the <u>displaced fluid</u>.



Aircraft experience a **lift** force vertically upwards. Lift is a mechanical aerodynamic force produced by the motion of the airplane through the air, perpendicular to the air flow direction.

Example 5

What is wrong with the following free body diagrams?

Description of motion	**Incorrect** Free-body diagram	Mistake(s)	**Correct** Free-body diagram
A block sliding along a frictionless horizontal surface with a constant velocity.			
A wagon pulled along a frictionless floor by a rope held at an angle of 30° above the horizontal.			
A book resting on a table.			

Example 6

In the following situations, draw the free body diagrams of the underlined body or system of bodies. Label all the forces.

(a) A <u>man</u> (standing stationary on the floor) with a <u>suitcase</u> in hand.

(b) An aircraft cruising at constant velocity in flight.

(c) A ship moving through the sea at constant velocity.

(d) A car towing a caravan, accelerating with acceleration ***a***. Draw for the car-caravan system too.

***LO* (g)** **recall and solve problems using the relationship *F* = *ma*, appreciating that resultant force and acceleration are always in the same direction**

Example 7

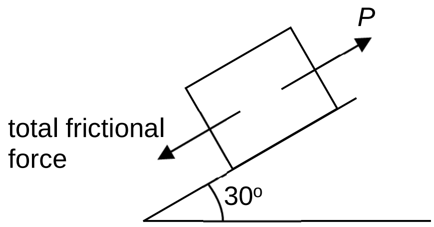
A model helicopter, of mass 5.0 kg, rises with constant acceleration from rest to a height of 600 m in 10.0 s. Calculate the upward thrust that is exerted by the rotor blades during the ascent.

Example 8

A car of mass 800 kg is moving up a hill inclined at 30º to the horizontal. The total frictional force on the car is 1000 N. Calculate the force *P* due to the engine on the car when the car is

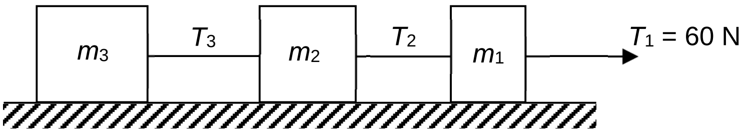
(i) accelerating up the plane at 2.0 m s^{-2},

(ii) moving with a steady velocity of 15 m s^{-1}.



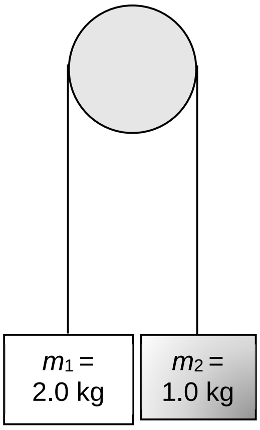
Example 9

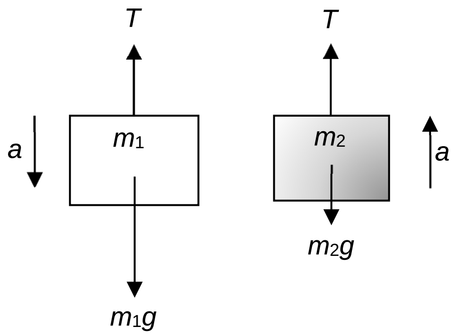
Three blocks are connected on a horizontal frictionless table and pulled to the right with a force T_1 = 60 N. If m_1 = 30 kg, m_2 = 20 kg and m_3 = 10 kg, find the tensions T_2 and T_3.



Example 10

Two masses m_1 and m_2 are connected by a cord passing over a smooth and light pulley and held in the position shown. Find the tension in the cord and the acceleration of the two bodies when they are released from rest.





***LO* (e)** **define and use impulse as the product of force and time of impact**

When we exert a force, F, on a body for a time period, t, we exert an impulse on the body.

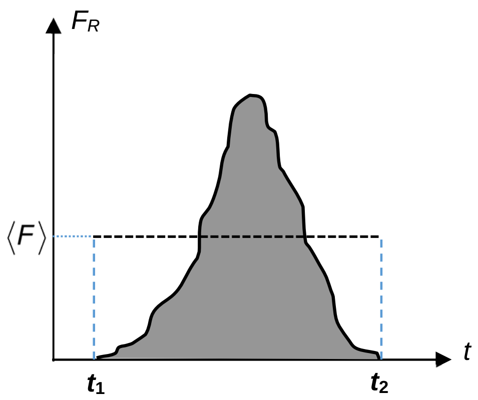
Impulse is defined as the product of average force F_{ave} and the time of impact Δt for which the average force acts.

Impulse = $F_{ave}\,\Delta t$ Unit: N s or kg m s^{-1}

Re-arranging Newton's 2nd Law of Motion, we have

$$F_R = m\frac{dv}{dt} \Rightarrow \underbrace{\int F_R dt}_{\text{impulse}} = m\int dv = m(\Delta v) = \underbrace{\Delta(mv)}_{\text{change in momentum}} = \Delta p$$

impulse = area under the force−time graph
= change in momentum

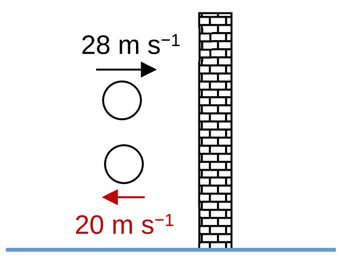


For the same change in momentum

$$\Delta p = \int_{t_1}^{t_2} F_R \cdot dt = \langle F \rangle (t_2 - t_1) = \text{impulse}$$

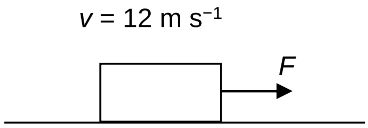
Example 11

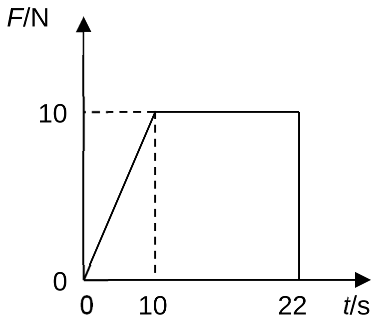
Consider a ball of mass 0.20 kg traveling with a velocity 28 m s^{-1} directly towards a wall. It hits the wall and bounces off in the opposite direction with a velocity of 20 m s^{-1}. Calculate the impulse due to the force by the wall.



Example 12

An object, mass 10 kg, moving with an initial speed of 12 m s^{-1} has a force acted on it for 22 s as shown.





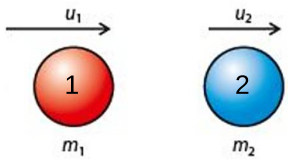
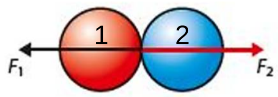
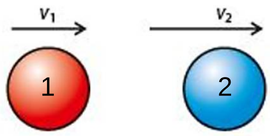
(a) Calculate the change in momentum after 25 s.
(b) What is the speed of the object at t = 25 s?
(c) Sketch the acceleration-time graph.
(d) Sketch the velocity-time graph.
(e) What is the average force on the object during the 22 s?

2. Conservation of Momentum

***LO* (h) state the principle of conservation of momentum**

The principle of conservation of momentum states that the total momentum of a system of bodies is constant provided no resultant external force acts on the system.

Justifying the Principle of Conservation of Linear Momentum

Suppose two bodies, of masses m_1 and m_2 collide with initial velocities be u_1 and u_2 respectively such that $u_1 > u_2$.	Before collision, 
When they collide, they will be deformed with forces acting on them. During the collision, body 1 exerts a force F_2 on body 2, and body 2 exerts a force F_1 on body 1. By Newton's 3rd law, these forces are equal and opposite: $$F_2 = -F_1$$ Both forces act for the same time Δt (however long the collision takes). Therefore, the impulses of the forces are equal and opposite.	During collision, 
Since impulse equals change in momentum, the changes in momentum of 1 and 2 are equal and opposite: $$\Delta p_2 = -\Delta p_1$$ By definition of change in momentum, $$m_2(v_2 - u_2) = -m_1(v_1 - u_1)$$	After collision, 

Rearranging the above equation gives

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

Total momentum of system before collision = Total momentum of system after collision

Note:
- There must be no resultant external force acting on the objects.
- Momentum is a vector quantity so direction must be taken into account.
- Momentum is conserved before, during, and after a collision.

Example 13

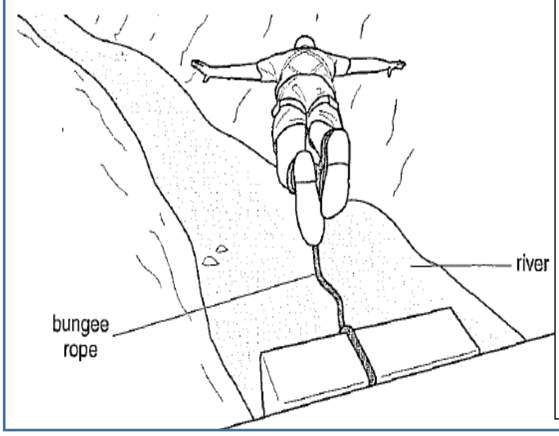
A 7.0 kg bowling ball of velocity *u* collides head-on with a 2.0 kg bowling pin. The pin flies forward with a velocity of 3.0 m s^{-1} and the ball continues with a velocity of 1.8 m s^{-1}. What was the initial velocity *u* of the ball?

Example 14

A gun of mass 1.0 kg has a bullet of mass 0.10 kg inside. The bullet leaves the gun when fired at a velocity of 200 m s^{-1}. Calculate the velocity of the gun after firing.

Example 15 ***[2008/H1/P2/Q6][part]***

The momentum of the person increases during free fall. Explain whether this is a violation of the principle of conservation of momentum.



***LO* (i)** **apply the principle of conservation of momentum to solve simple problems including inelastic and (perfectly) elastic interactions between two bodies in one dimension (knowledge of the concept of coefficient of restitution is not required)**

Types of Collisions

Elastic Collisions

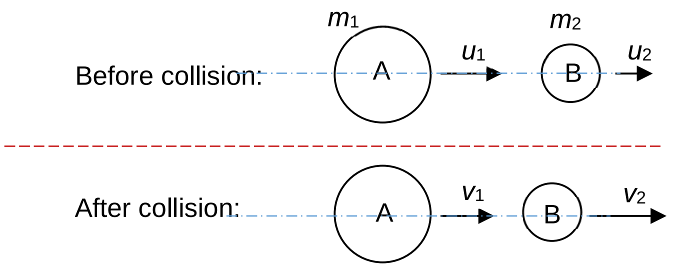
- Total momentum is conserved.
- Total kinetic energy is conserved.
- relative speed of approach = relative speed of separation.

Inelastic Collisions

- Total momentum is conserved.
- Total kinetic energy is <u>not</u> conserved.
- For completely inelastic collision: The 2 bodies coalesce after collision.

<u>**Elastic Collision**</u>

***LO* (j)** **show an understanding that, for a (perfectly) elastic collision between two bodies, the relative speed of approach is equal to the relative speed of separation**

<table>
<tr><td>Consider two bodies A and B colliding head-on elastically with each other.
The initial speeds of A and B are u_1 and u_2 respectively, where $u_1 > u_2$.
After the collision, A and B move off with final speeds v_1 and v_2 respectively, where $v_2 > v_1$.</td><td>
</td></tr>
<tr><td>From Conservation of Momentum, taking rightward as positive:
$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$ ----- (1)</td><td>By Conservation of Kinetic Energy:
$\frac{1}{2}m_1{u_1}^2 + \frac{1}{2}m_2{u_2}^2 = \frac{1}{2}m_1{v_1}^2 + \frac{1}{2}m_2{v_2}^2$ ----- (2)</td></tr>
<tr><td>Rewriting (1) gives:
$m_1(u_1 - v_1) = m_2(v_2 - u_2)$ ----- (3)</td><td>Rewriting (2) gives:
$m_1(u_1^2 - v_1^2) = m_2(v_2^2 - u_1^2)$
$m_1(u_1 + v_1)(u_1 - v_1) = m_2(v_2 + u_2)(v_2 - u_2)$ ----- (4)</td></tr>
<tr><td colspan="2">(4) ÷ (3) gives:
$u_1 + v_1 = v_2 + u_2$
or $\boxed{u_1 - u_2 = v_2 - v_1}$ ----- (5)

i.e. for elastic collisions, relative speed of approach = relative speed of separation</td></tr>
</table>

Example 16 **(Relative speed of approach and separation)**

In each case, the velocities of two bodies **A** and **B** are represented.
Assuming that rightwards is the positive direction, what is the relative speed (of approach or separation) in each case?

(a)	**A** → 4 m s^{-1}	**B** → 3 m s^{-1}	Relative speed of **A** approaching **B** =
(b)	**A** → 4 m s^{-1}	← 3 m s^{-1} **B**	Relative speed of **A** approaching **B** =
(c)	**A** → 3 m s^{-1}	**B** → 4 m s^{-1}	Relative speed of **B** separating from **A** =
(d)	← 3 m s^{-1} **A**	**B** → 4 m s^{-1}	Relative speed of **B** separating from **A** =

Example 17

A 25.0 kg ball moving to the right at 20.0 m s^{-1} catches up and collides elastically with a 10.0 kg ball moving in the same direction at 15.0 m s^{-1}. Find the velocity of each object after the collision.

Example 18

A 10.0 kg ball moving to the right at 10.0 m s^{-1} makes an elastic head-on collision with a 15.0 kg ball moving to the left at 30.0 m s^{-1}. Find the velocity of each object after the collision.

***LO* (k)** **show an understanding that, whilst the momentum of a closed system is always conserved in interactions between bodies, some change in kinetic energy usually takes place.**

<u>Inelastic collision</u>

In most collisions, kinetic energy is not conserved although the momentum is conserved. The decrease in kinetic energy of the system is transferred to heat and sound, or is used to change the shape of the bodies involved.

An inelastic collision in which the colliding bodies stick together (coalesce) and move off as one body after the collision is called a **completely inelastic collision.**

<u>Example 19</u>

A cue ball of mass 0.15 kg initial velocity 5.0 m s^{-1} collides head-on with a billiard ball of mass 0.20 kg initially at rest. After the collision, the billiard ball moves with a velocity of 4.0 m s^{-1}.

(a) Calculate the velocity of the cue ball after the collision.

(b) Is the collision elastic?

<u>Example 20</u>

A ball A of mass 0.10 kg moves with a velocity of 6.0 m s^{-1} undergoes completely inelastic head-on collision with ball B of mass 0.20 kg initially at rest. Find the velocity of ball A after collision.

Note:
We may not know the directions of the balls/objects after collision. To solve the problem, we need to assume of the direction. If we obtain a negative value, it indicates movement in the opposite direction.

End of Lecture

ANNEX

(A) <u>Three special cases for elastic collisions</u>

From (5) on Page 16

$$v_2 = u_1 - u_2 + v_1 \text{ ----- (6)}$$

Sub (6) into (3):

$$m_1(u_1 - v_1) = m_2(u_1 - u_2 + v_1 - u_2)$$
$$\Rightarrow m_1u_1 - m_1v_1 = m_2u_1 - 2m_2u_2 + m_2v_1$$
$$\Rightarrow (m_1 + m_2)v_1 = (m_1 - m_2)u_1 + 2m_2u_2$$
$$\Rightarrow v_1 = \frac{(m_1 - m_2)}{(m_1 + m_2)}u_1 + \frac{2m_2}{(m_1 + m_2)}u_2 \text{ ----- (7)}$$

Similarly, we can obtain:

$$v_2 = \frac{2m_1}{(m_1 + m_2)}u_1 + \frac{(m_2 - m_1)}{(m_1 + m_2)}u_2 \text{ ----- (8)}$$

Note:
It is not advisable to memorize (7) and (8). Instead, you should derive these from the Conservation of Momentum and Conservation of Kinetic Energy.

From (7) and (8),

1. Two identical masses collide i.e. $m_1 = m_2$, e.g. two billiard balls collide with each other.

   $v_1 = u_2$ $v_2 = u_1$

   That means that the two masses exchange velocities after the collision.

2. An extremely large mass, m_1 collides with a very small mass at rest, m_2, i.e. $m_1 >> m_2$, e.g. bowling ball hit a stationary ping pong.

   $v_1 \approx u_1$ $v_2 \approx 2u_1$

   The large mass m_1 continues with a speed close to its initial speed, while the small mass m_2 bounces off with a speed about twice the initial speed of m_1.

3. A very small mass m_1 collides with a very large mass at rest, m_2, i.e. $m_2 >> m_1$, e.g. a ping pong striking a wall.

   $v_1 \approx -u_1$ $v_2 \approx 0$

   The small mass m_1 rebounds with a speed close to its initial speed, and the large mass remains almost stationary.

Definition List

Force	Force is directly proportional to the rate of change of momentum. The direction of the force is in the direction of the change of momentum.
Newton's First Law	An object at rest will remain at rest and an object in motion will remain in motion at constant velocity in the absence of an *external resultant* force.
Newton's Second Law	The rate of change of momentum of a body is directly proportional to the resultant force acting on the body and occurs in the direction of the resultant force.
Newton's Third Law	If body A exerts a force on body B, then body B exerts a force of the same type that is equal in magnitude and opposite in direction on body A. Note: Same type means if one is gravitational force, the other one must be gravitational force too.
Inertia	The reluctance of a body to change its state of rest or uniform motion in a straight line.
Mass	The amount of matter or substance in the body. It is a measure of body's inertia to changes in velocity.
Weight	The force acting on a mass due to a gravitational field.
One newton	Defined as the force which when it acts on a body of mass 1 kg causes the body to have an acceleration of 1 m s^{-2}. (1 N = 1 kg m s^{-2})
Linear momentum	The linear momentum of a body is the product of the mass and its velocity. The linear momentum is in the same direction as its velocity.
Impulse	Product of constant force F and the time duration Δt for which the constant force acts. Impulse = $F \cdot \Delta t$.
Impulse-Momentum Theorem	The impulse of a force acting on an object is equal to the change in momentum of the object.
Principle of Conservation of Momentum	The principle of conservation of linear momentum states that the total momentum of a *system* of bodies is constant provided no resultant *external* force acts on the system.
Elastic collision	The total momentum and total kinetic energy are the same before and after the collision. Note: If the number of marks given is 3, the following can be included *in addition* to the answer above: The relative velocity of approach equals relative velocity of separation.
Inelastic collision	Total kinetic energy is not the same before and after the collision, although total momentum is conserved.
Perfectly inelastic collision	The total kinetic energy is not the same before and after the collision, although total momentum is conserved, AND, the objects stick together after collision.
All collisions	Total momentum and total energy are conserved. Note: For collision of nuclear particles, Total momentum and Total mass-energy are conserved.

Tutorial Questions

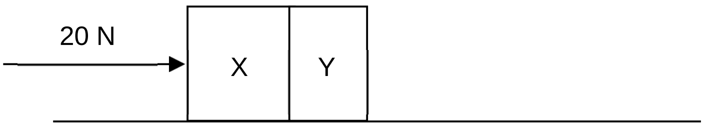
Part 1: Newton's Laws of Motion

1. A footballer accelerates a football horizontal from rest to a speed of 10 m s^{-1} during the time in which his toe is in contact with the ball for 0.20 s. If the football has a mass of 0.50 kg, what average force does the footballer exert on the ball? [25 N]

2. The air exerts a forward force of 10 N on the propeller of a 0.20 kg model plane. If the plane accelerates forward at 2.0 m s^{-2}, what is the magnitude of the resistive force exerted by air on the airplane? [9.6 N]

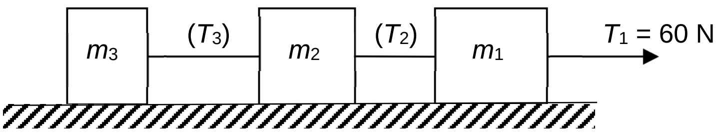
3. A 5.0 g bullet leaves the muzzle of a rifle with a speed of 320 m s^{-1}. What net force (assumed constant) is exerted on the bullet while it is moving down the 0.82 m long barrel? [312 N]

4. Two blocks, X and Y, of masses 3 kg and 2 kg respectively, are accelerated along a floor by a force 20 N applied to block X, as shown in the diagram. Given that the frictional forces that the floor acts on X and Y are 6 N and 4 N respectively,



(a) Draw free body diagrams showing how the forces act on X and Y.
(b) Base on Newton's second law, write three equations that govern the motion of the objects.
(c) What are their acceleration(s)? [2 m s^{-2}]
(d) What is the magnitude of the force exerted by block Y on block X? [8 N]

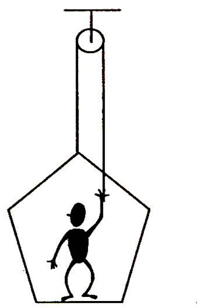
5. Three blocks are connected on a horizontal frictionless table and pulled to the right with a force T_1 = 60 N. If m_1 = 30 kg, m_2 = 20 kg and m_3 = 10 kg, find the tensions T_2 and T_3. [30 N, 10 N]



6. Determine the force that an 80 kg man exerts on the floor of an elevator when it
(a) is at rest;
(b) rises with a constant velocity of 2.0 m s^{-1};
(c) descends with a constant velocity of 2.0 m s^{-1};
(d) rises with a constant acceleration of 2.0 m s^{-2};
(e) descends with a constant acceleration of 2.0 m s^{-2}
(f) accelerating downwards at 9.81 m s^{-2}

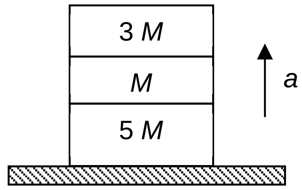
[785 N, 785 N, 785 N, 945 N, 625 N, 0 N]

7. The figure shows a painter in a crate which hangs alongside a building. When the painter pulls on the rope, the force he exerts on the floor of the crate is 300 N. If the mass of the painter and the crate is 75 kg and 25 kg respectively, find the acceleration of the crate. [2.2 m s^{-2} upwards]



8. Three crates of masses 3*M*, *M* and 5*M* are stacked on top of one another on the floor of a lift as shown on the right.

   When the lift is accelerating upwards with an acceleration *a*, the magnitude of the force mass *M* exerts on the mass 5*M* is given by



   A $4Mg - 5Ma$

   B $4Mg - 4Ma$

   C $4Mg + 4Ma$

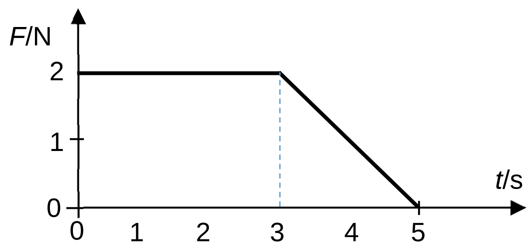
   D $4Mg + 5Ma$

Part 2: Linear Momentum and Impulse

9. A 0.10 kg ball is thrown straight up into the air with an initial speed of 15 m s^{-1}. Find the momentum of the ball,
   (a) at its maximum height [0 kg m s^{-1}]
   (b) halfway to its maximum height [1.06 kg m s^{-1}]

10. A car is stopped by a traffic signal. When the light turns green, the car accelerates, increasing the speed uniformly from 0 to 5.20 m s^{-1} in 0.832 s. For a 70.0 kg passenger in the car during this time, what is,
   (a) the magnitudes of the impulse and [364 N s]
   (b) the average force experienced [438 N]

11. The force shown in the force-time graph acts on 1.5 kg mass in the positive *x*-axis direction. Calculate,
   (a) the impulse of the force, [8 N s]
   (b) the final velocity of the mass if it is initially at rest, and [5.3 m s^{-1}]
   (c) the final velocity of the mass if it is initially moving along x-axis with a velocity of –2.00 m s^{-1}. [3.33 m s^{-1}]



12. Explain why, when catching a fast-moving ball, the hands are drawn back while the ball being brought to rest. Discuss whether your explanation has any bearing on the use of crushable boxes for packing eggs.

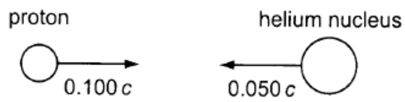
13. Two objects are known to have the same momentum. Do they have the same kinetic energy?

14. Consider a ball of mass 0.20 kg traveling with a velocity 28 m s^{-1} directly towards a wall. It hits the wall and bounces off in the opposite direction with a velocity of 28 m s^{-1}. Calculate the impulse due to the force by the wall. [11 kg m s^{-1} to the left away from the wall]

Part 3: Principle of Conservation of Momentum

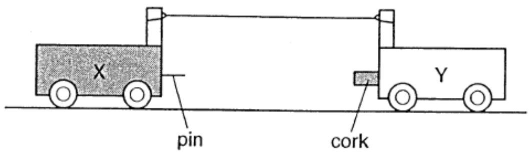
15. A 730 N man stands in the middle of a frozen pond of radius 5.0 m. He is unable to get to the other side because of the lack of friction between his shoes and the ice. To overcome this difficulty, he throws his 1.2 kg physics textbook horizontally towards the north shore, at a speed of 5.0 m s^{-1}. How long does it take him to reach the south shore? [62 s]

16. A proton (mass 1 *u*) travelling with velocity of +0.100*c* collides elastically head-on with a helium nucleus (mass 4 *u*) travelling with velocity −0.050*c.*



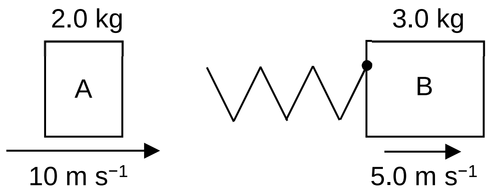
What are the velocities of each particle after the collision?
[proton: −0.140*c*; helium nucleus: +0.010*c*]

17. The diagram shows two trolleys X and Y held stationary and connected by an extended elastic cord. The mass of X is twice that of Y.



The trolleys are released at the same instant. They move towards each other and stick together on impact. Just before the collision, the speed of X is 20 cm s^{-1}. What is the speed of Y after the collision?
[0 m s^{-1}]

18. Block A of mass 2.0 kg moves with a velocity of 10 m s^{-1} on a smooth horizontal table. Block B of mass 3.0 kg moves with a velocity of 5.0 m s^{-1} in front of A in the same direction. A light spring of force constant, k = 1000 N m^{-1} is attached to B as shown in the following figure.



When A collides with B, there will be an instant when the spring experiences maximum compression.

(a) Calculate the maximum compression of the spring, x. (Elastic potential energy stored in a spring = ½ kx^2) [0.173 m]

(b) Calculate the velocity of A and B after they are separated. [4.0 m s^{-1}, 9.0 m s^{-1}]

19. A ball of clay is thrown against a wall. The clay sticks to the wall and stops. Explain how the principle of conservation of momentum applies in this case.

20. A fast moving neutron with an initial velocity u has a head-on elastic collision with a stationary proton. After the collision, the velocity of the neutron is v and that of the proton is w. Taking the masses of the neutron and proton to be equal, which one of the following statements is false?

(a) $u + v = w$
(b) $u^2 = v^2 + w^2$
(c) The speed of the proton after the collision is the same as that of the neutron before the collision.
(d) The proton and the neutron move off in opposite directions with equal speeds.

End of Tutorial