CHAPTER 4: DYNAMICS

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

Introduction to Dynamics

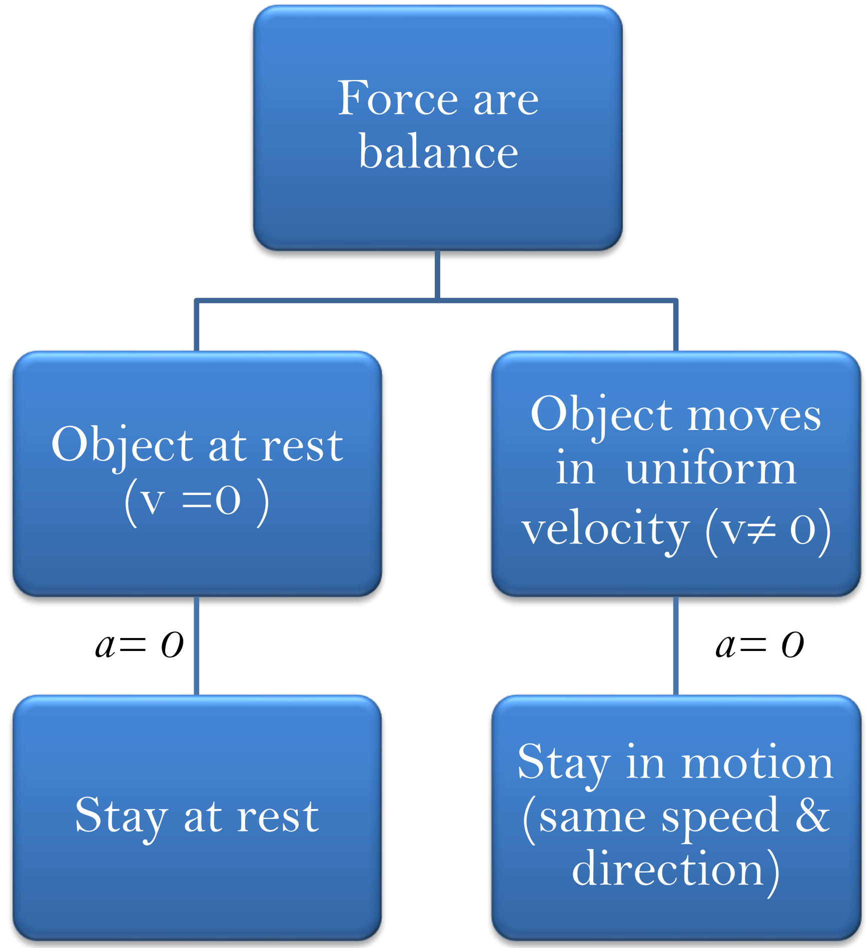
- In a previous chapter of study (kinematics), the variety of ways by which motion can be *described* (words, graphs, diagrams, numbers, etc.) have been discussed.
- In **dynamics**, we will study of the causes of motion. *We are going to look at how we can explain of object moves in term of the forces which change its motion*
- *Firstly,* we will study about Newton's Laws of Motion.

Newton's Law

- Isaac Newton (a 17th century scientist) came up with three laws about forces and motion that explain why objects move (or don't move).
- His three laws of motion have become known as *Newton's three laws of motion*.
- Newton's first law of motion - sometimes referred to as the **law of inertia**.

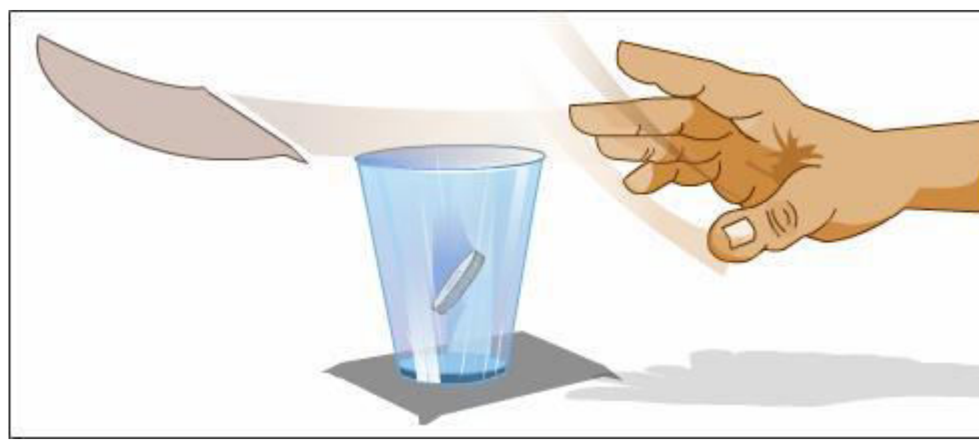
Newton's Laws of motion: 1^{st} Law:

- An object will remain at rest or in a state of uniform motion in a straight line, unless it is acted on by a net external force or unbalanced force.
- Or we can say:
- An object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force."



Inertia

- From Newton's 1st Law, we realize that objects tend to "keep on doing what they're doing."
- In fact, it is the natural tendency of objects to resist changes in their state of motion.
- This tendency to resist changes in their state of motion is described as **inertia**.



Mass and Inertia

- The tendency of an object to resist changes in its state of motion varies with mass.
- The more inertia that an object has, the more mass that it has.
- A more massive object has a greater tendency to resist changes in its state of motion
- Object with higher inertia is much difficult
  - To start moving
  - To change direction
  - To stop moving

Question

- Supposing you were in space in a *weightless environment*, would it require a force to set an object in motion?
- Yes
- Even in space, objects have mass. And if they have mass, they have inertia. That is, an object in space resists changes in its state of motion. A force must be applied to set a stationary object in motion. Newton's laws rule - everywhere!

Balanced & unbalanced force

Free body diagrams

Introduction to force

Force

- We know that a force can be a **push** or a **pull** acting on an object
- There are possible for more than 1 force acting on an object at one time
- Examples:
  - Lifting something
  - Dragging something
  - Floating Globe

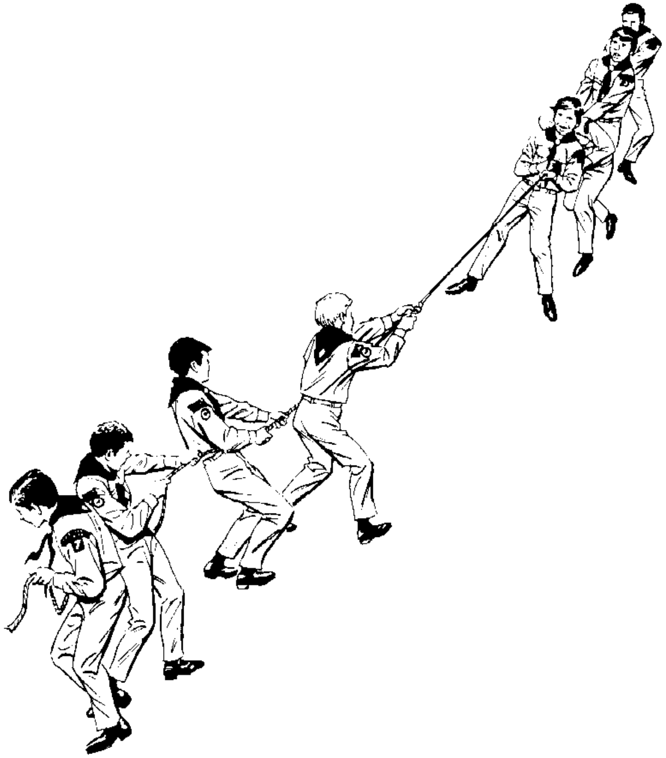
Balanced force

Balanced forces.

- If two **equal forces** are applied to an object in opposite directions, the object does not move / or moves as a constant speed.

Unbalanced forces

- If two **unequal forces** are applied to an object in opposite directions, and the object does move.



Effect of unbalanced force

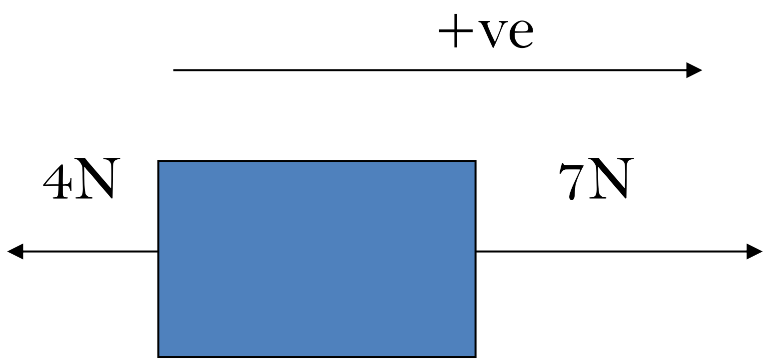
- If the forces acting on an object are not balanced then the object with either:
  - Speed up (accelerate)
  - Slow down (decelerate)
  - Change direction
  - Change its shape

Free body diagrams

- Free-body diagrams are diagrams used to show the relative magnitude and direction of all forces acting upon an object
- Rules:
  - Depict all the forces that exist for that object in the given situation
  - Take account of the direction of each force.
- We can calculate the **resultant force** by adding up forces which act in the same straight line.
  - Non zero resultant force means unbalanced forces.

Example

A block has 2 opposing forces being applied to it: 7N to the right and 4N to the left.



To Calculate the **Resultant Force ($\mathbf{F_{net}}$)**,

- Add forces in the same straight line.
- 7N – 4N = **3N (to the right)**

F net = 3N

Balance and unbalanced force

- By using free body diagram, we can know the resultant force on an object
- Forces on an object are balanced if the resultant or net forces on the object is equal to zero.
  - Thus, the object will either remain at rest or have a constant velocity.

Problem:

- A man of mass 75kg has a weight of 750N sit on a table. This 750N will act downward on the table and the table will exert a 750N force upwards on the man. The forces are balanced.
- What would happen if the upward force were less than 750N?

The table leg will break and the man fall onto the floor

Force down 750N

Force up 750N

Newton's 2nd law and 3rd law of motion

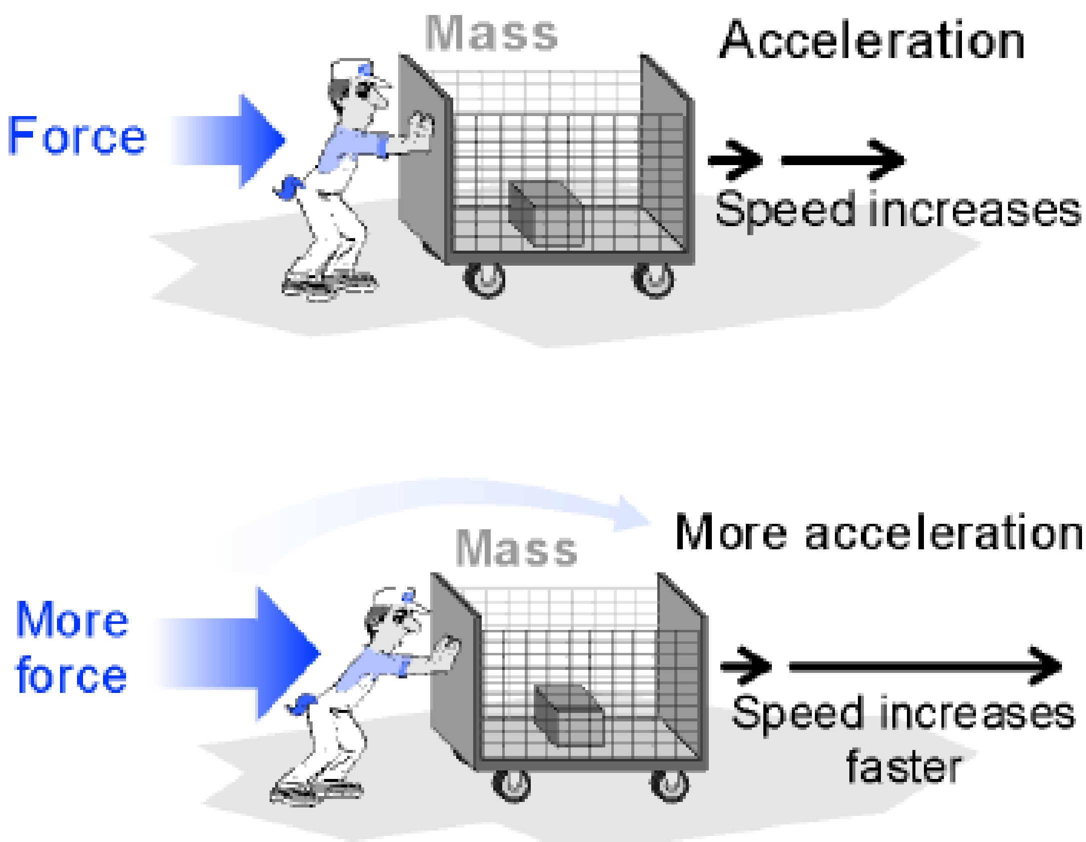
Newton's Laws of motion: 2nd Law

- *For a body of constant mass, its acceleration is directly proportional to the net force applied to it*

- *Force = mass* x *acceleration*
- $F = ma$
- *Unit of force = Newton (N)*
  - ***One Newton*** *is defined as* *unit of force which will give a mass of 1kilogram an acceleration of 1ms*$^{-2}$ *in the direction of the force*

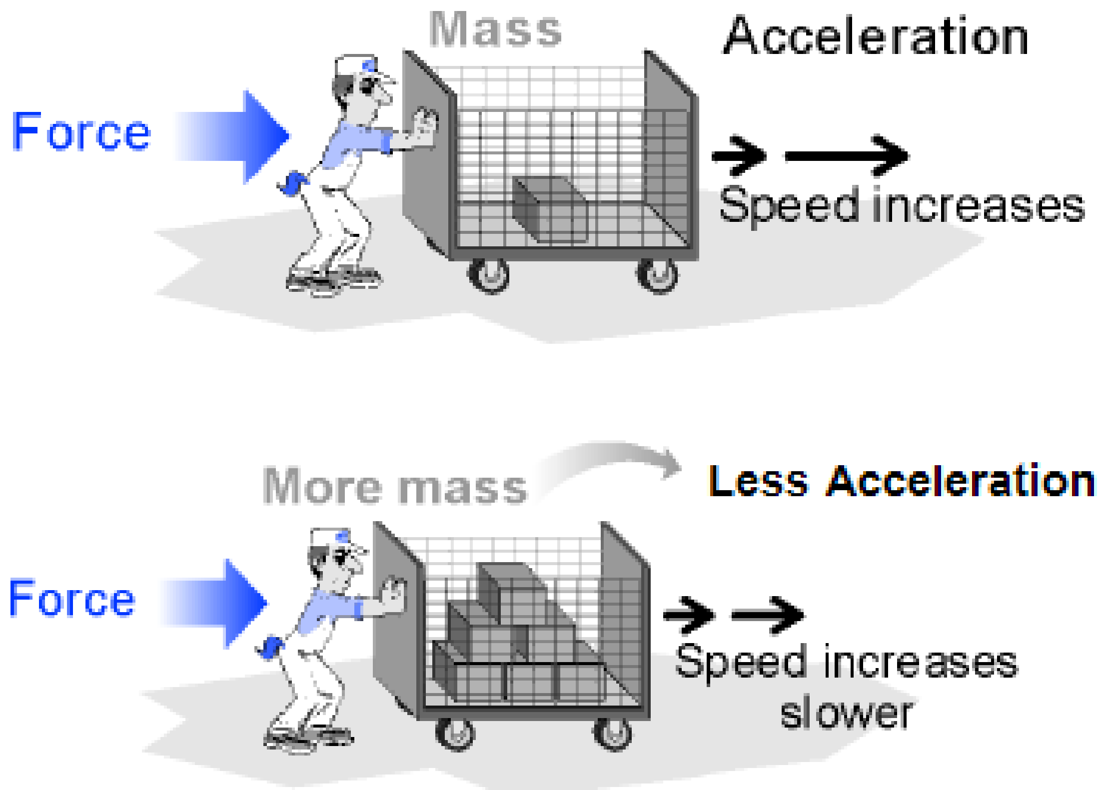
Newton's Second Law

- If you apply <u>more</u> force to an object, it accelerates at a higher rate.



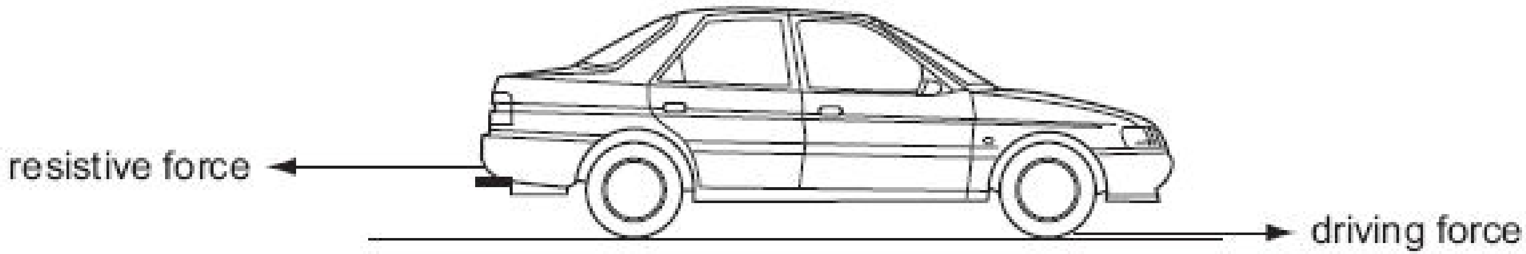
Newton's Second Law

- For the same force, object with higher mass accelerates at a lower rate because mass has inertia.



Problem

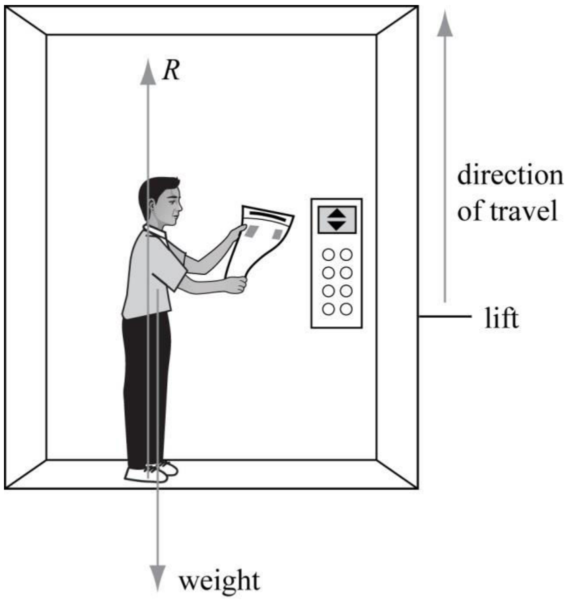
- A car of mass 750 kg has a horizontal driving force of 2.0 kN acting on it. It has a forward horizontal acceleration of 2.0 m s^{-2}.



- What is the resistive force acting horizontally?

0.5 kN

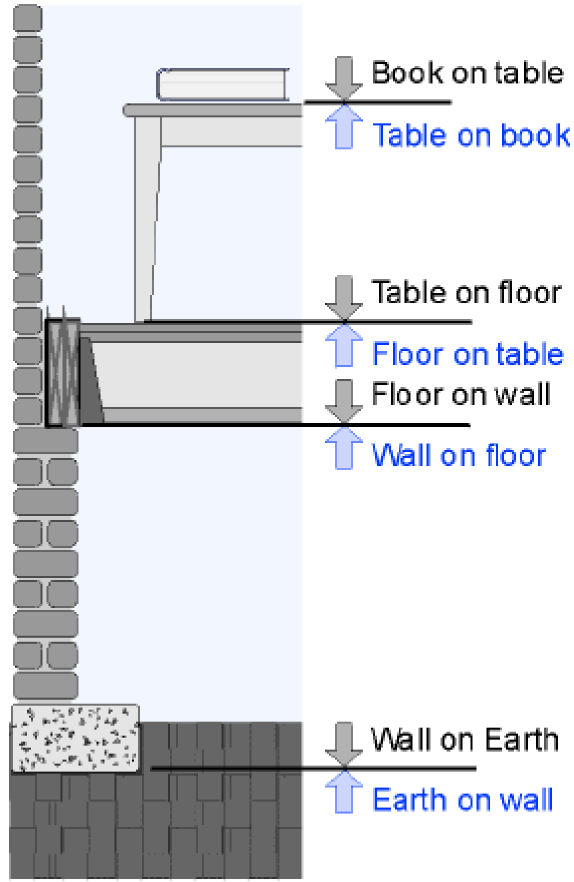
Problem



- The diagram shows an 80 kg person in a lift.
- The normal contact force acting on the person from the base of the lift is R. Determine the magnitude of R when the lift:
  a) is travelling upwards at a constant velocity of 2.0 m s^{-1} $\boxed{780 \text{ N}}$
  b) is accelerated upwards at 2.3 m s^{-2}. $\boxed{970 \text{ N}}$

Newton's Laws of motion: 3rd Law

- Whenever one body exerts a force on another, the second exerts an equal and opposite force on the first
- Or
- When two body interact, the forces they exert on each other are equal in magnitude and opposite in direction



Newton's Laws of motion: 3^{rd} Law

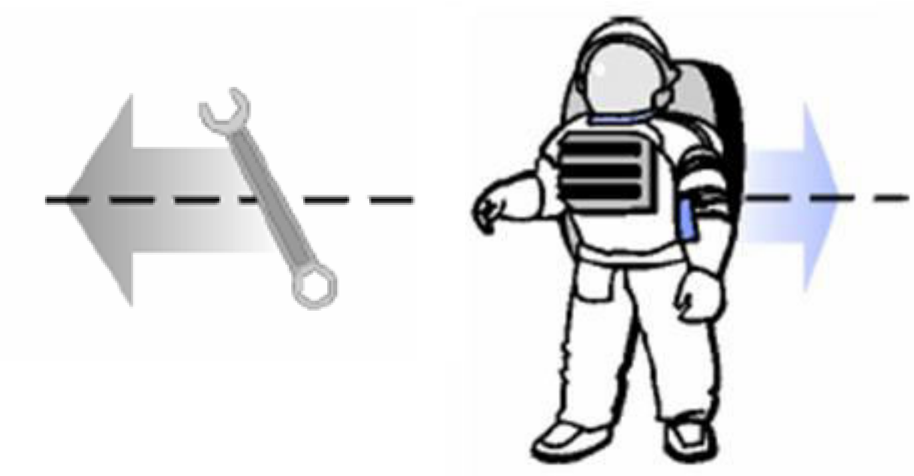
- The two forces appear at the same time
- The two forces have these following characteristics
  - They act on different objects
  - They are equal in magnitude
  - They are opposite in direction
  - They are forces of the same type

Type of interaction (3^{rd} Law)

- Two objects may attract each other because of the gravity of their masses - gravitational force
- Two objects may attract or repel because of their electrical charges – electrical force
- Two objects touch – contact force
- Two objects may be attached by a string and pull on each other – tension force
- Two objects may attract or repel because of their magnetic field

Problem: Newton's Third Law

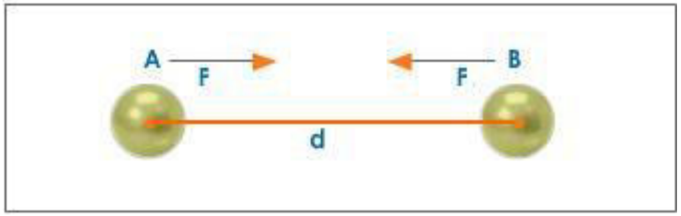
- The astronauts working on the space station have a serious problem when they need to move around in space: There is nothing to push on.
- Can you suggest what the astronaut should do?
- The solution is to throw something opposite the direction you want to move.
- This works because *all forces always come in pairs.*

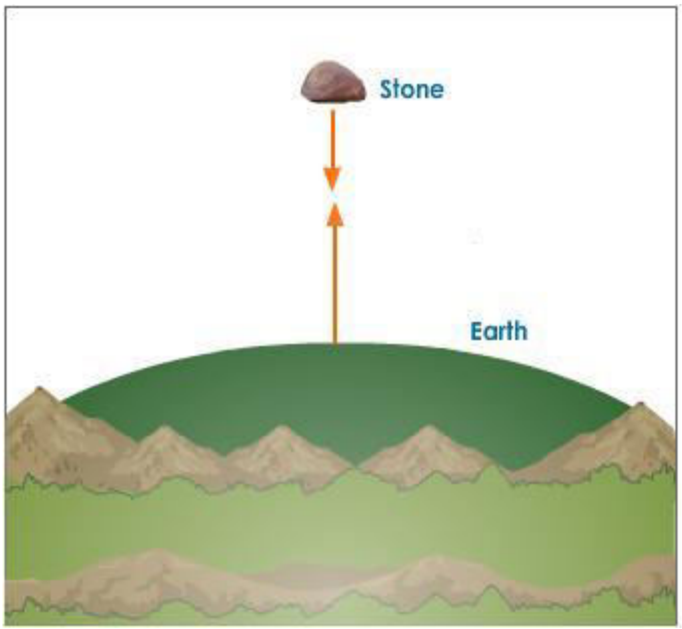


- Gravitational force & gravitational field
- Mass and weight
- Identifying forces
- Terminal velocity

WEIGHT & FORCE

Gravitational force





Gravitational Force of Attraction Between the Earth and the Stone

- The gravitational force is always **attractive**. We never get a repulsive gravitational force.
- When a stone is dropped from a height it falls towards the Earth.
- It is because the Earth exerts a force on the stone and the stone also exerts an equal force on the Earth.
- Why we do not see the Earth moving towards the stone. ?

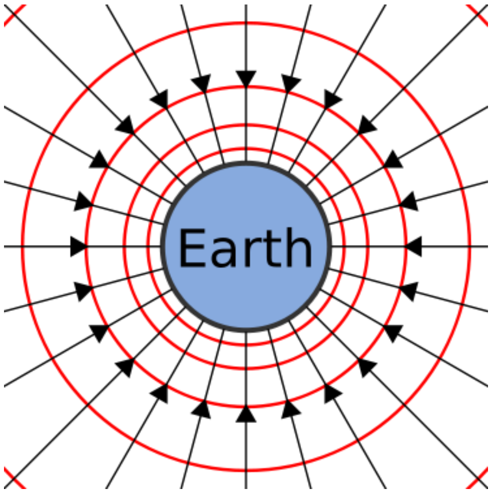
Gravitational force

- According to the second law of motion
  - whenever a force is acting on an object, it produces acceleration in it. The gravitational force of attraction produces acceleration both in the Earth and in the stone.
- It is the gravitational force, which produces acceleration in both Earth and the stone.
- Acceleration produced due to the gravitational force is higher in the case of the stone as its mass is very small whereas the acceleration produced in the Earth will be negligible as the Earth is massive.

$$\text{Acceleration produced in the object} = \frac{\text{Force acting on the object}}{\text{Mass of the object}}$$

- Hence, displacement of Earth is negligible. We don't see Earth moves

Gravitational field



Gravitational field

- **Field** is a region in which a force is felt.
- **Force of gravitational attraction can be represented** as a field
- **Gravitational field** is the space around a body within which its gravitational force of attraction is experienced.
- The **closer the field line, the stronger** the **gravitational field an object will experience.**

Mass and weight

- The mass of an object is always the same, but its weight can change based on the strength of the gravitational field.
- The stronger the gravitational field, the stronger the gravitational force will be exerted on a mass in that field
- For example, the mass of an object would be the same on the moon as it was on Earth, but its weight would be different due to the different gravitational forces.

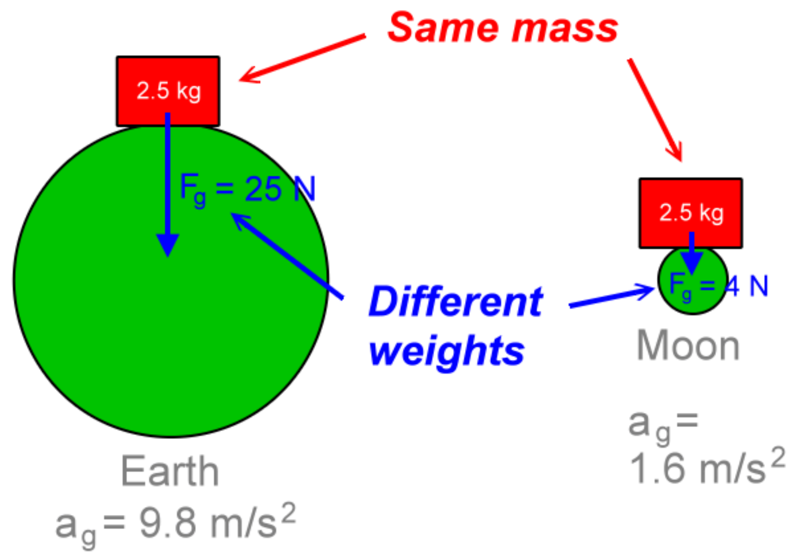
Mass and weight

$$W = mg$$

weight

mass

Gravitational field strength

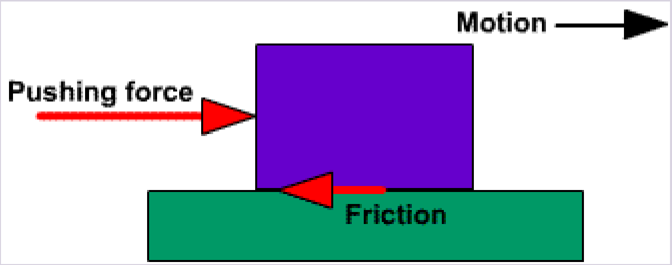
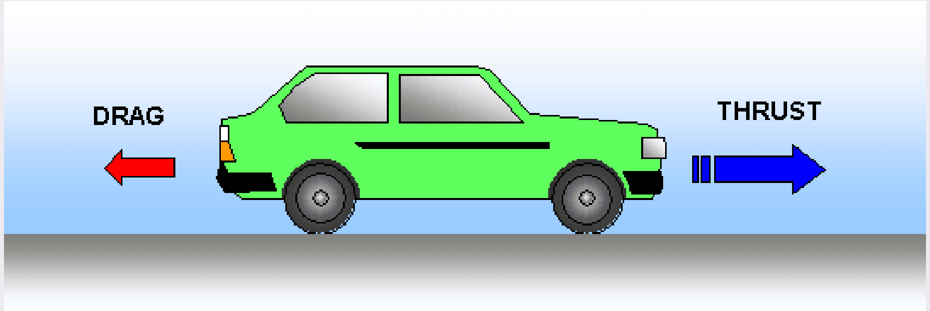


- Weight is the gravitational force acting on the object
  - Unit of weight = Newton (N)
  - Unit of gravitational field strength = Nkg^{-1}
  - Example: a mass of one kilogram has a weight of 9.8 N
- Mass is constant but weight is depend on gravitational field strength

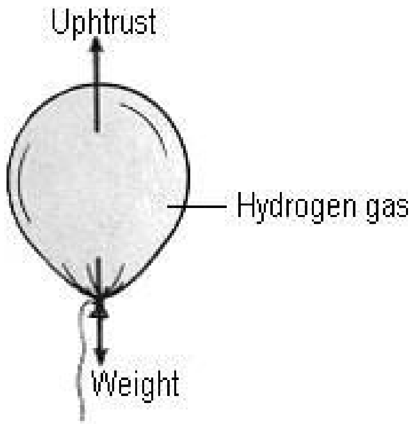
Identifying forces

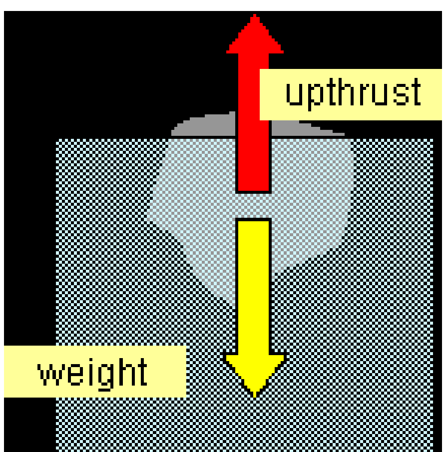
Contact forces	Non-contact forces
Friction	Gravitational force
Drag	Electric force
Tension	Magnetic force
Normal	
Spring force	

Friction and Drag

Type of forces	Description
Friction	The force which arises when two surfaces rub over one another. Always in the opposite direction of the motion 
Drag	A force that opposes the motion through liquid or gases (fluid) 

Upthrust





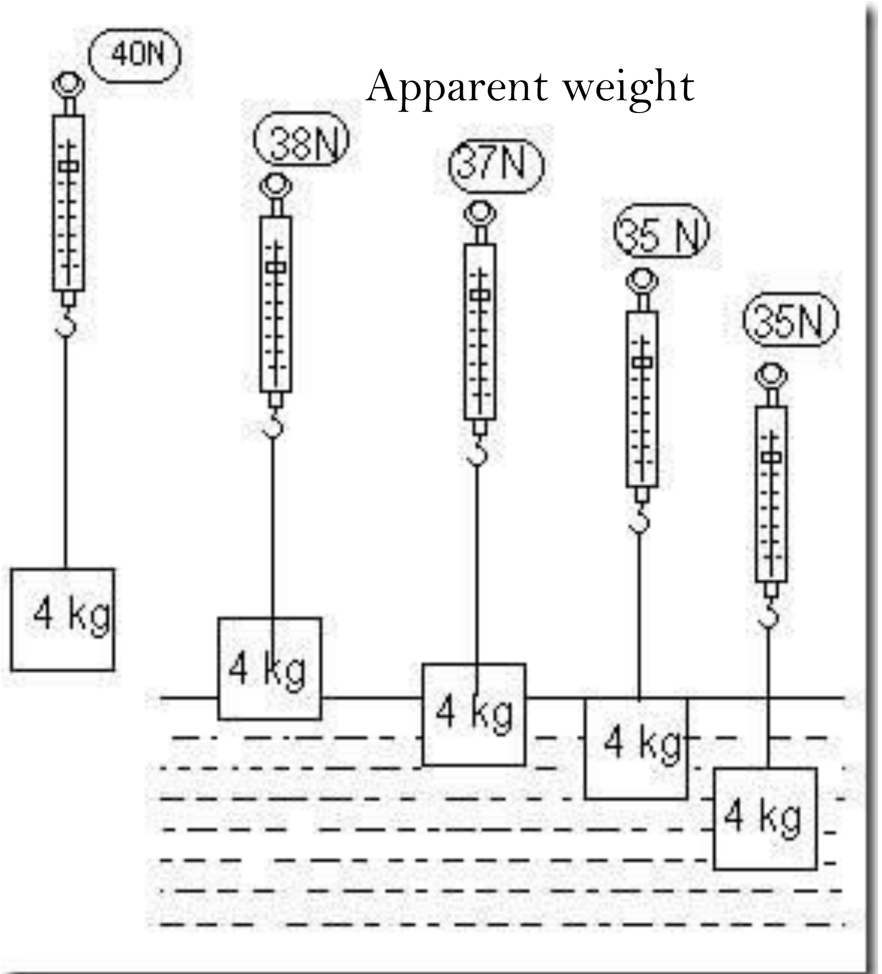
Type of forces	Description
Upthrust	✓Force experience by an object immersed in fluid such as water or air ✓A floating object displaces its own weight of liquid ✓Upthrust = $\rho V g$

When an object floats in a liquid the upthrust is equal to the weight of the object itself - the net force on the object is zero.

Buoyancy force / Upthrust

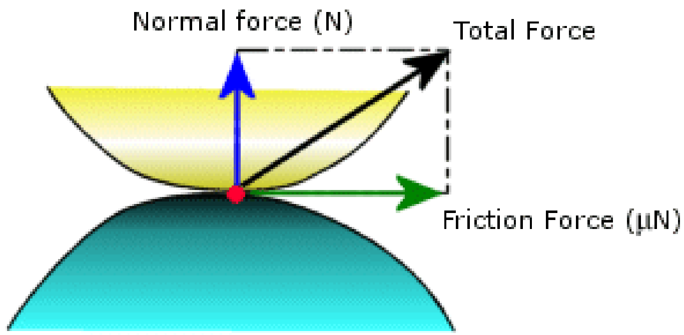
Weight in air

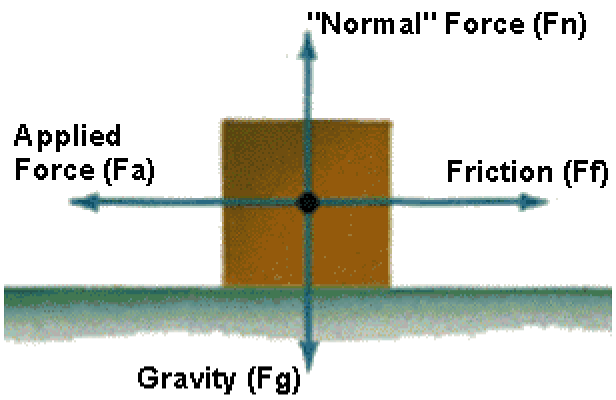
Apparent weight



- When an object is immersed partially or completely in a fluid, the weight of the object **reduce** and it is called as **apparent weight**.
- The **apparent weight** depends on the weight of **water dispersed/displaced**.
- The **apparent weight** is caused by an **upward force** exerted by the fluid on the object and the force is known as **Buoyancy Force** or **Upthrust**

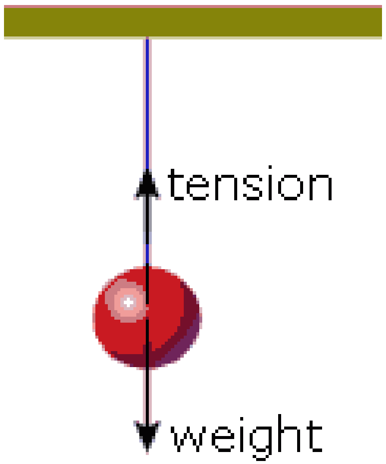
Contact force





- Contact force occurs between object and its surface
- Contact force sometimes known as the normal reaction force
- Contact force always act at right angles to the surface which produces it.

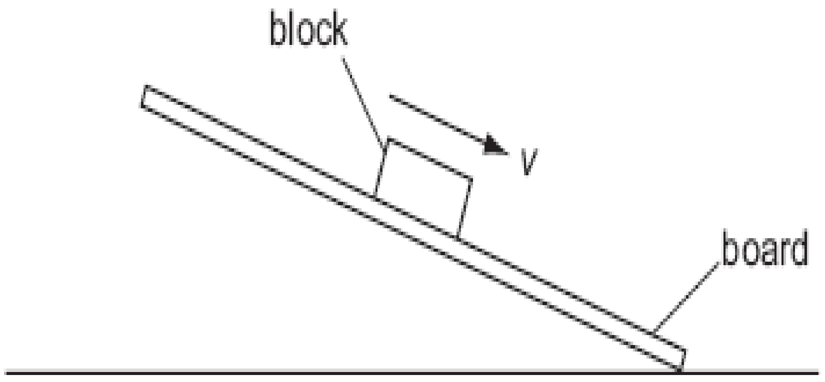
Tension force



- Tension force is the force in a rope or string when it is stretched
- If we pull on the end s of a string, it tends to stretch.
- It tries to shorten the string.
- The tension in the string pulls back against us.
- Tension can also act in spring. If we stretch a spring, the tension pulls back to try to shorten the spring. If we compress the spring, the tension acts to expand the string

Problem

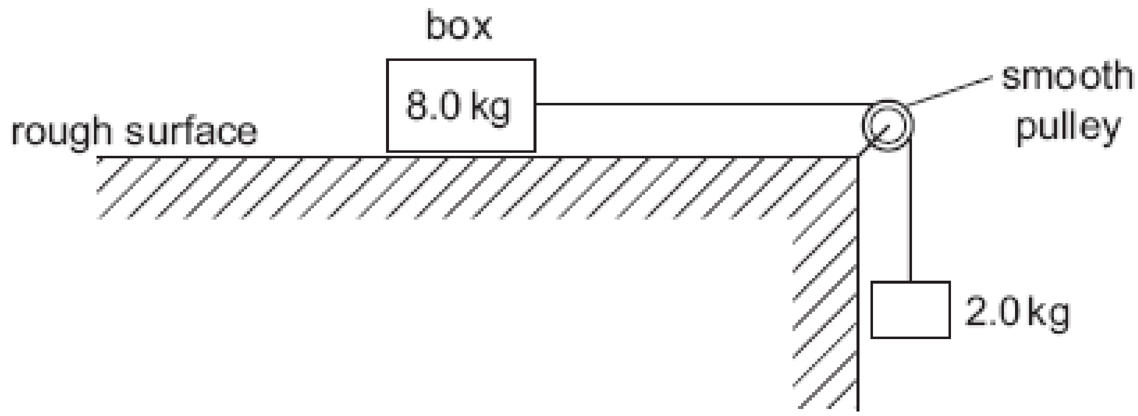
A wooden block rests on a rough board. The end of the board is then raised until the block slides down the plane of the board at constant velocity *v*. Which row describes the forces acting on the block when sliding with constant velocity?



	frictional force on block	resultant force on block
A	down the plane	down the plane
B	down the plane	zero
C	up the plane	down the plane
D	up the plane	zero

Problem

- A box of mass 8.0 kg rests on a horizontal, rough surface. A string attached to the box passes over a smooth pulley and supports a 2.0 kg mass at its other end.

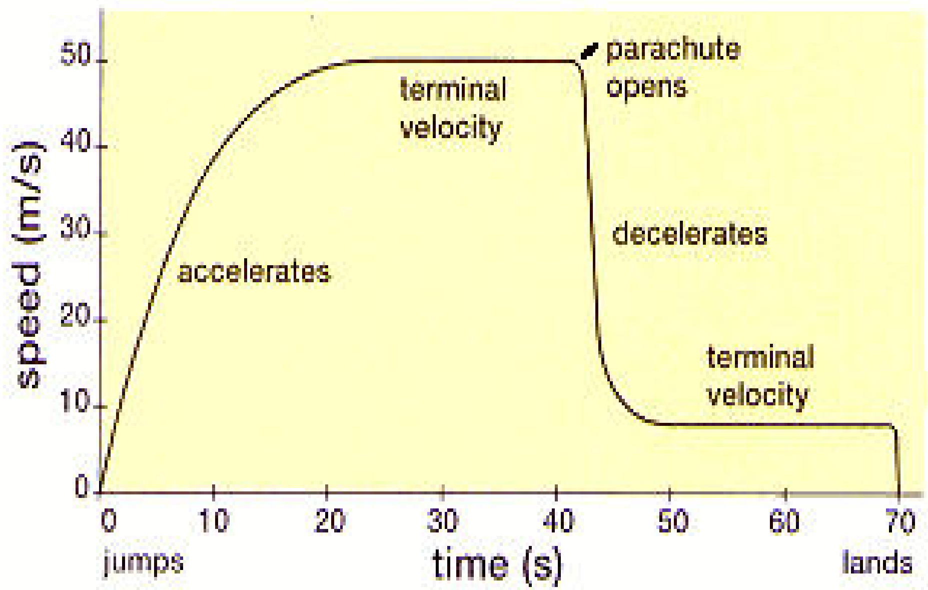


- When the box is released, a friction force of 6.0 N acts on it.
- What is the acceleration of the box? $1.4\ ms^{-2}$

Terminal velocity

- When objects accelerate towards the ground due to gravity they experience an increasing air resistance force up.
- **When the force due to air resistance** reach an **equal value to the weight** of the falling object, there is no resultant force and therefore no acceleration.
- The object will travel at a **constant speed.** This is called the **terminal velocity.**
- **Terminal velocity occur for motion of object in fluid**

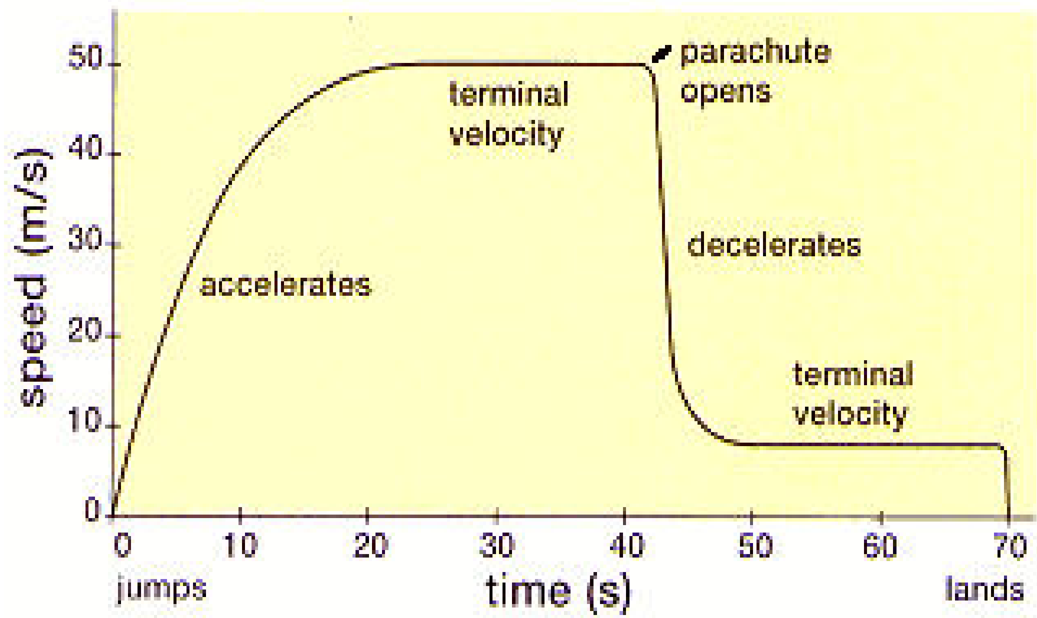
Terminal Velocity –a skydiver example



Time to open the parachute. This dramatically increases the air resistance, so the parachutist slows down greatly *("decelerates")*.

For a few seconds, the air resistance is greater than her weight. As she decelerates, the air resistance decreases.

Terminal Velocity –a skydiver example



She's slowed down, and now the **forces are back in balance**.

Her **speed** is **constant** again - she has a **new**, much slower, **terminal velocity**.

THINK

- Is it only a falling objects that have a terminal velocity?

Momentum & its conservation

MOMENTUM

Definition of Momentum

- Momentum is defined as product of mass and its velocity.
- Momentum is represented by the symbol p, and is a ***vector quantity.***

$$p = mv \text{ ; unit} = \text{kgms}^{-}$$

momentum= *mass* x *velocity*

- Momentum has both magnitude and direction. Its direction is same as the direction of the object's velocity
- Like energy, momentum is also conserved as long as there is no external force acts on the system

Principle of Conservation of Momentum:

- *Within a closed system, the total momentum in any direction is constant*
- Or
- *For a closed system, in any direction: total momentum of objects before collision = total momentum of objects after collisions*

Total momentum before = total momentum after

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

- This equation is valid for any collisions in a closed system

Impulse and change of momentum

- **Impulse is** the product of the force and the time over which the force acts on an object
- Force x time interval = change in momentum

$$F \times \Delta t = \Delta p$$
$$= mv - mu$$

- Or we can say,
  - *impulse of a force equal to the change in momentum*
- Unit of impulse is $kgms^{-1}$ or Ns
- Momentum can also be calculated as
  - **final momentum – initial momentum**

- Perfectly elastic collision / head on elastic collision
- Inelastic collision

COLLISIONS

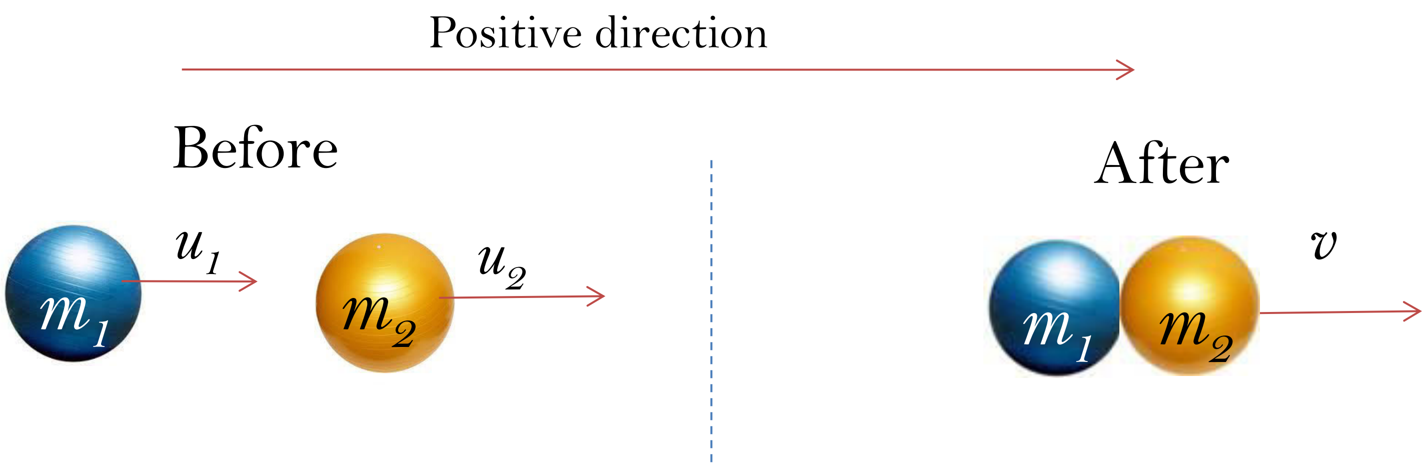
Inelastic Collisions

- Principle of conservation of momentum is still applied

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

- Kinetic energy before collision is not equal to kinetic energy after collision because it can be transformed to another energy such as heat or sound energy during collision
- However, total energy are still conserve (base on conservation of energy principle)

Inelastic collision - object travel together



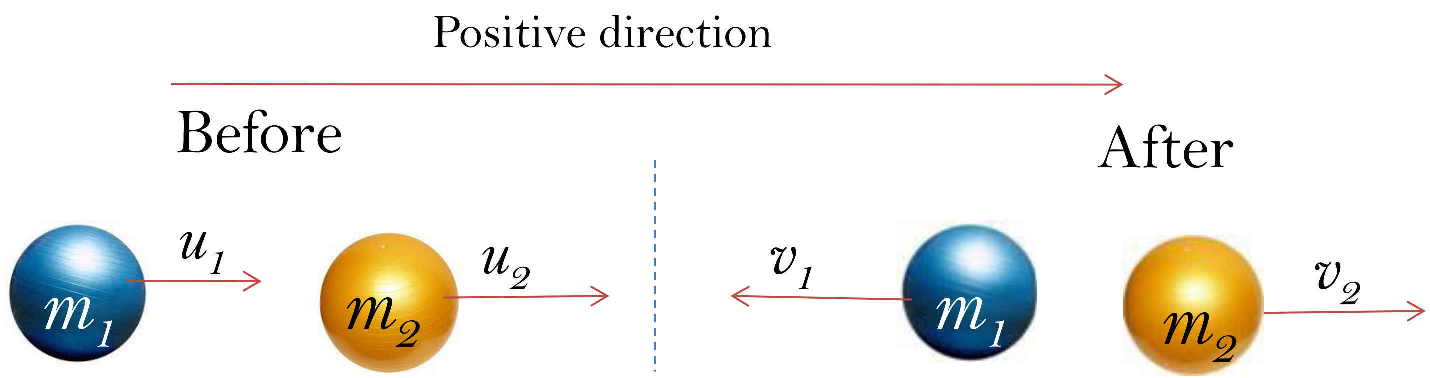
- Using principle of conservation of momentum

$$\mathbf{m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2}$$

- We get

$$m_1u_1 + m_2u_2 = (m_1+m_2)v$$

Inelastic collision – object travel separately



- Using principle of conservation of momentum

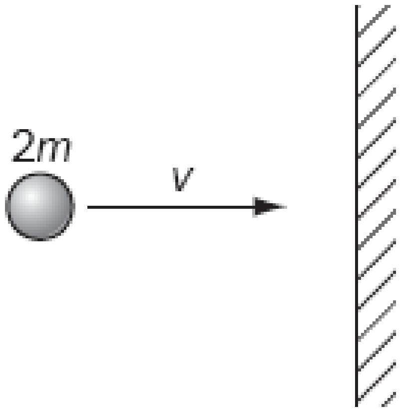
$$\mathbf{m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2}$$

We get

- $m_1u_1 + m_2u_2 = m_1(-v_1) + m_2v_2$

Problem

- A particle of mass $2m$ and velocity v strikes a wall. The particle rebounds along the same path after colliding with the wall. The collision is inelastic.



- What is a possible change in the momentum of the ball during the collision?

A mv **B** $2mv$ **C** $3mv$ **D** $4mv$

Problem

- Which quantities are conserved in an inelastic collision?

	kinetic energy	total energy	linear momentum
A	conserved	not conserved	conserved
B	conserved	not conserved	not conserved
C	not conserved	conserved	conserved
D	not conserved	conserved	not conserved

Perfectly elastic collision

1. **Momentum** is always conserved in any collision.

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

- And we know that if objects bounce off each other after collision, the collision is **elastic**

2. **But, in perfectly elastic collision** or always refer as **head on elastic collision**, the total kinetic energy before is equal (**conserved**) with the kinetic energy after collision.

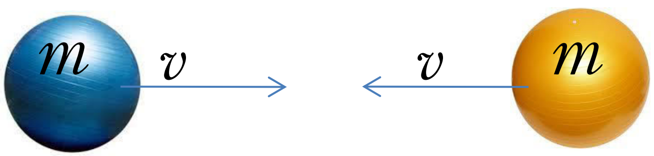
Kinetic energy before = kinetic energy after

$$\tfrac{1}{2} m_1u_1^2 + \tfrac{1}{2} m_2u_2^2 = \tfrac{1}{2} m_1v_1^2 + \tfrac{1}{2} m_2v_2^2$$

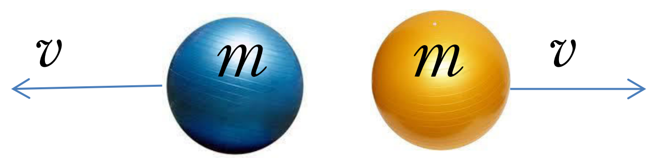
Perfectly elastic collision

Positive direction

Before



After



Total momentum

$mv + (-mv) = 0$

Equal

Total momentum

$-mv + mv) = 0$

Kinetic energy

$\frac{1}{2}\, mv2 + \frac{1}{2}\, m(-v^2) = mv^2$

Equal

Kinetic energy

$\frac{1}{2}\, m(-v^2) + \frac{1}{2}\, mv^2 = mv^2$

Perfectly elastic collision

Before

Relative **speed** of approach

Formula: u_1-u_2

In this case:

$v - (-v) = 2v$

Equal

After

Relative **speed** of separation

Formula : $v_2 - v_1$)

In this case:

$v - (-v) = 2v$

3. Thus, in perfectly elastic collision

Relative **speed** of approach = Relative **speed** of separation

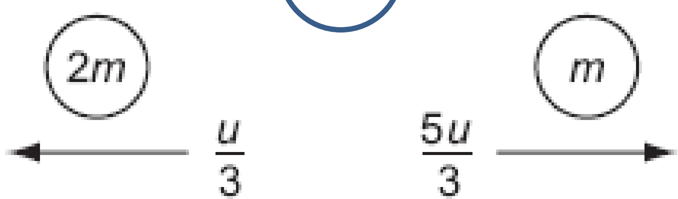
$$u_1 - u_2 = v_2 - v_1)$$

Problem

- Two spherical masses approaching each other head-on at an equal speed u. One has mass 2m and the other has mass m.

- Which diagram, showing the situation after the collision, shows the result of an elastic collision?

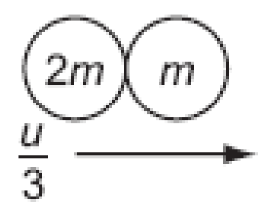
A



B

C

D



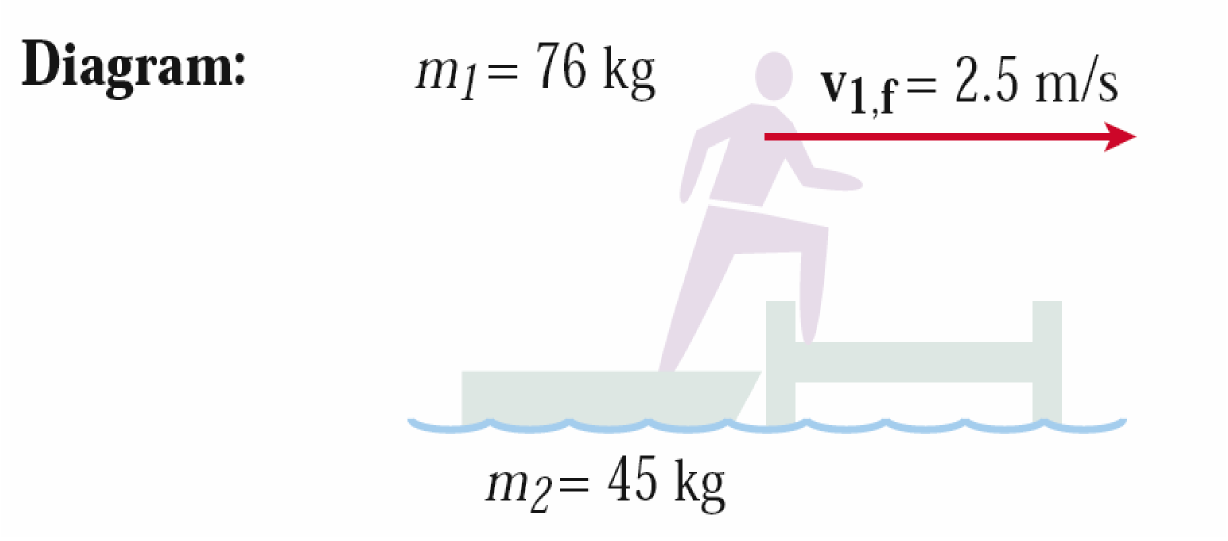
the spheres stick together

Question

A light body and a heavy body have the same momentum, which has the greater kinetic energy

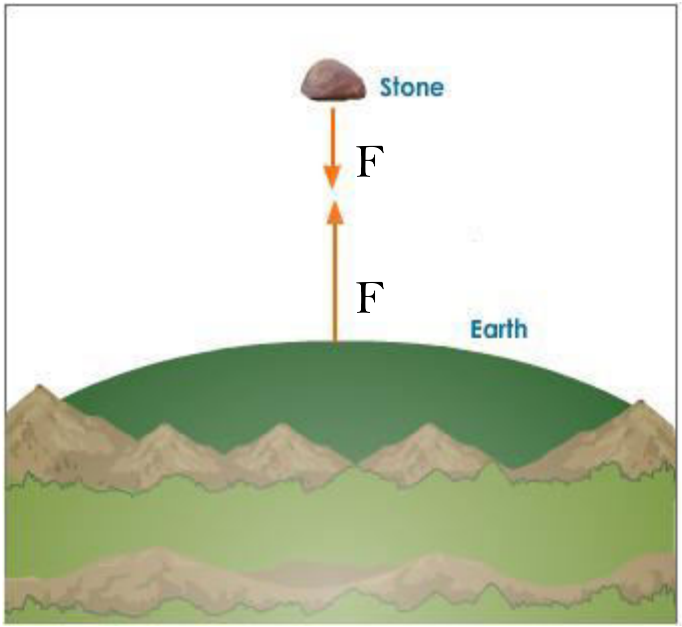
Question

A 76 kg boater, initially at rest in a stationary 45 kg boat, steps out of the boat and onto the dock. If the boater moves out of the boat with a velocity of 2.5 m/s to the right, what is the final velocity of the boat?



$V_2 = 4.2$ m/s to the left

Object falling towards earth

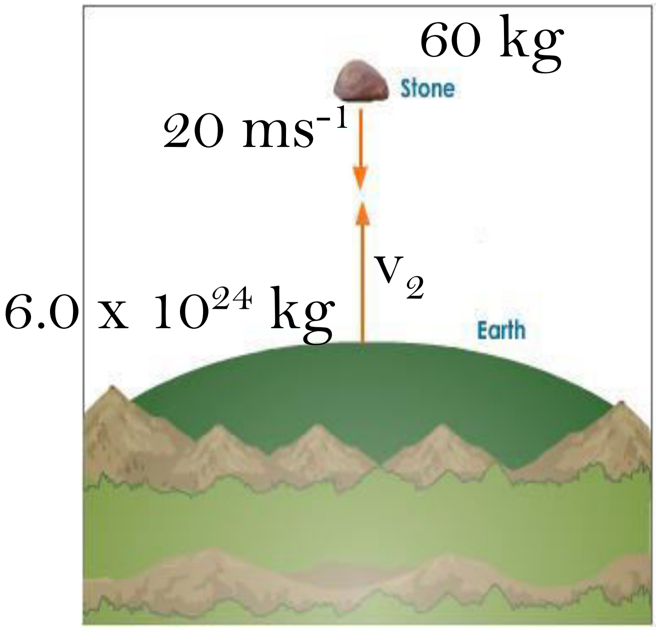


- If we push a stone over a cliff it will falls and its speed increases as it falls.
- The stone actually gains momentum downwards.
- However as Newton's third law reminds us, every force has an equal and opposite force
- Here, the **gravitational force of the Earth on the ball** causes the ball to accelerate, and thus gain momentum.
- However there is an equally strong force of the ball on the Earth, **pulling the Earth** up to meet the ball.

Object falling towards earth

- But, the mass of the Earth is so large that the acceleration caused by the ball's gravity is usually negligible.
- Change in momentum of the Earth is equal in magnitude but opposite in direction to the change in momentum of the ball.
- Thus the net change in momentum is zero and the law of conservation of momentum is validated.

Object falling towards earth



- Let say stone with mass 60 kg is falling towards earth at a speed of 20 ms^{-1} . Mass of earth is 6.0×10^{24} kg
- Calculate the velocity of earth moving towards it.
- Initially: total momentum of earth and rocks = 0 (both initially at rest). Hence:

- $0 = m_1v_1 + m_2v_2$
- $-m_1v_1 = m_2v_2$
- $60\ (20) = -\ 6.0 \times 10^{24}$ kg (v_2)
- $v_2 = -\ 2.0 \times 10^{-22}\ ms^{-1}$
- (negative means earth moves in the opposite direction to the rock)

Define Newton's Law of Motion By Momentum

Newton's 1st Law

- When we say that an object is moving, it means, it has momentum.
- However, it also means that the object has a tendency to keep on moving.
- A big lorry moves with velocity v on a road is much difficult to stop compared to a car moving also at velocity v.
- This is because the lorry has higher momentum
- The idea of keep on moving is what has been confirmed in Newton's 1st Law.

1^{st} Newton's law by momentum definition

- 1^{st} Newton's law
  - *An object at rest stays at rest and an object in motion stays in motion with the same speed and in the same direction unless acted upon by an unbalanced force."*
- Newton's first Law in term of momentum
  - *Momentum of an object remains constant unless there is an external force acts on the object*

2^{nd} Newton's law by momentum definition

- 2^{nd} Newton's law:
  - *For a body of constant mass, its acceleration is directly proportional to the net force applied to it*
- Newton's second law in momentum definition:
  - *The resultant force acting on an object is equal to the rate of change of its momentum. (net force & the change in momentum are in the same direction)*

$$Force = rate\ of\ change\ of\ momentum$$
$$= \Delta p/t$$

- Means, if an object's momentum is changing, there must be a force acting on it

THE END

Tutorials

9 An object of mass 4.0 kg moving with a speed of $3.0\,\text{m}\,\text{s}^{-1}$ strikes a stationary object in an inelastic collision.

Which statement is correct?

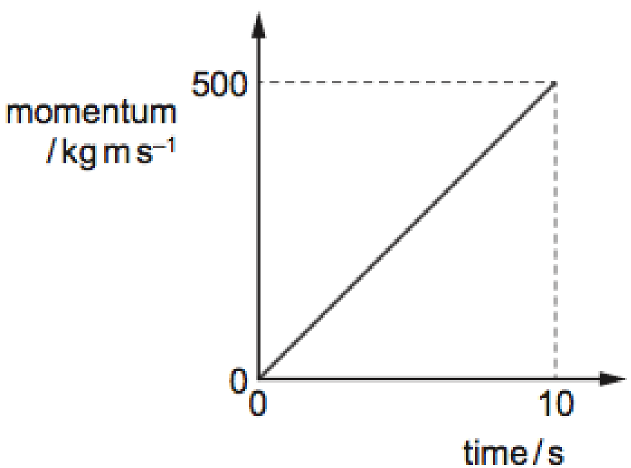
A After collision, the total kinetic energy is 18 J.

B After collision, the total kinetic energy is less than 18 J.

C Before collision, the total kinetic energy is 12 J.

D Before collision, the total kinetic energy is less than 12 J.

10 The graph shows how the momentum of a motorcycle changes with time.



What is the resultant force on the motorcycle?

A 50 N **B** 500 N **C** 2500 N **D** 5000 N

13 An object of mass m travelling with speed v has a head-on collision with another object of mass m travelling with speed v in the opposite direction. The two objects stick together after the collision.

What is the total loss of kinetic energy in the collision?

A 0 **B** $\frac{1}{2}mv^2$ **C** mv^2 **D** $2mv^2$

14 Two identical spheres X and Y approach each other with the speeds shown and undergo a head-on elastic collision.

What are the velocities of the spheres after the collision?

	sphere X	sphere Y
A	$0\,\mathrm{m\,s^{-1}}$	$2\,\mathrm{m\,s^{-1}}$ →
B	$2\,\mathrm{m\,s^{-1}}$ →	$4\,\mathrm{m\,s^{-1}}$ →
C	$2\,\mathrm{m\,s^{-1}}$ ←	$4\,\mathrm{m\,s^{-1}}$ →
D	$4\,\mathrm{m\,s^{-1}}$ ←	$2\,\mathrm{m\,s^{-1}}$ →

11 Trolley X, moving along a horizontal frictionless track, collides with a stationary trolley Y. The two trolleys become attached and move off together.

Which statement about this interaction is correct?

A Some of the kinetic energy of trolley X is changed to momentum in the collision.

B Some of the momentum of trolley X is changed to kinetic energy in the collision.

C Trolley X loses some of its momentum as heat in the collision.

D Trolley X shares its momentum with trolley Y but some of its kinetic energy is lost.

S13 QP11

10 Which of the following is a statement of the principle of conservation of momentum?

A In an elastic collision momentum is constant.

B Momentum is the product of mass and velocity.

C The force acting on a body is proportional to its rate of change of momentum.

D The momentum of an isolated system is constant.

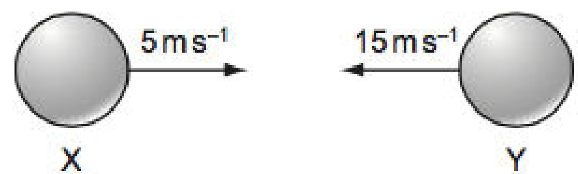
S15 QP13

11 A moving object strikes a stationary object. The collision is inelastic. The objects move off together.

Which row shows the possible values of total momentum and total kinetic energy for the system before and after the collision?

	total momentum before collision / $kg\,m\,s^{-1}$	total momentum after collision / $kg\,m\,s^{-1}$	total kinetic energy before collision / J	total kinetic energy after collision / J
A	6	2	90	30
B	6	6	30	90
C	6	6	90	30
D	6	6	90	90

12 Two balls X and Y are moving towards each other with speeds of $5\,m\,s^{-1}$ and $15\,m\,s^{-1}$ respectively.



They make a perfectly elastic head-on collision and ball Y moves to the right with a speed of $7\,m\,s^{-1}$.

What is the speed and direction of ball X after the collision?

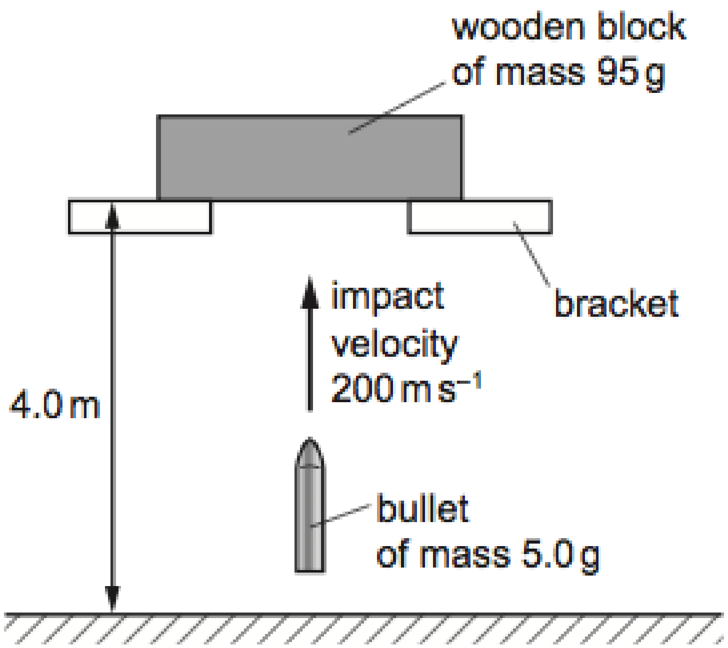
A $3\,m\,s^{-1}$ to the left

B $13\,m\,s^{-1}$ to the left

C $3\,m\,s^{-1}$ to the right

D $13\,m\,s^{-1}$ to the right

13 A wooden block is freely supported on brackets at a height of 4.0 m above the ground, as shown.



A bullet of mass 5.0 g is shot vertically upwards into the wooden block of mass 95 g. It embeds itself in the block. The impact causes the block to rise above its supporting brackets.

The bullet hits the block with a velocity of 200 m s^{-1}. How far above the ground will the block be at the maximum height of its path?

A 5.1 m **B** 5.6 m **C** 9.1 m **D** 9.6 m

11 Two spheres travel along the same line with velocities u_1 and u_2. They collide and after collision their velocities are v_1 and v_2.

Which collision is **not** elastic?

	u_1 / m s^{-1}	u_2 / m s^{-1}	v_1 / m s^{-1}	v_2 / m s^{-1}
A	2	–5	–5	–2
B	3	–3	0	6
C	3	–2	1	6
D	5	2	3	6