**Dynamics**

# Motion

# Summary

**Speed** is a measure of the distance travelled by an object in a unit of time.

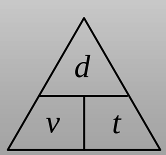
Speed is measured in metres per second (m $s^{-1}$).

**Speed, Distance and Time**

m

$$speed = \frac{distance}{time}$$

m $s^{-1}$ s




$$v = \frac{d}{t}$$

$$d = vt$$

$$t = \frac{d}{v}$$

**Average speed**, $\bar{v}$, is a measure of the average of the speed for an entire journey.

- measure distance travelled with a ruler
- measure time taken to travel with a stop clock
- average speed = $\frac{\text{distance travelled}}{\text{time taken}}$

**Instantaneous speed**, $v$, is the speed at one point during the journey.

- measure length of card attached to vehicle with a ruler
- measure time taken for card to pass through a light gate with an electronic timer
- instantaneous speed = $\frac{\text{length of card}}{\text{time through light gate}}$

**Scalar** quantities only have a magnitude (size)

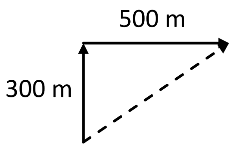
Distance and speed are scalar quantities; as are time, frequency, energy and mass.

**Vector** quantities have both magnitude (size) and direction

Velocity and displacement are vector quantities; as are acceleration and force.

When adding vector quantities they must be added "nose-to-tail". This can be done by scale diagram or using trigonometry

e.g. A displacement of 300 m North then 500 m East



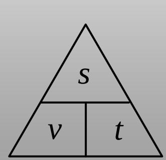

resultant = 583 m @ 059

**Velocity, Displacement and Time**

m

$$velocity = \frac{displacement}{time}$$

m $s^{-1}$ s




$$v = \frac{s}{t}$$

$$s = vt$$

$$t = \frac{s}{v}$$

**Acceleration** is a measure of the rate of change of velocity of an object.

Acceleration is measured in metres per second per second (m $s^{-2}$).

Acceleration can be calculated by dividing the change in velocity by the time taken for the change.

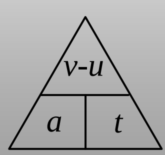
The two velocities can be determined experimentally by using either:

- a single card and two light gates connected to an electronic timer

  or
- a double card and a single light gate connected to an electronic timer

**Acceleration, Velocity and Time**

$$\overbrace{acceleration}^{\text{m s}^{-2}} = \frac{\overbrace{final\ velocity - initial\ velocity}^{\text{m s}^{-1}}}{\underbrace{time}_{\text{s}}}$$

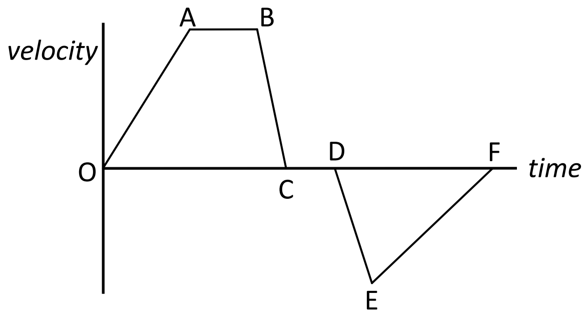



$$a = \frac{v-u}{t}$$

$$v - u = at$$

$$t = \frac{v-u}{a}$$

A **velocity-time graph** shows how the velocity of a moving object varies with time.




OA – constant acceleration

AB – constant velocity

BC – constant deceleration

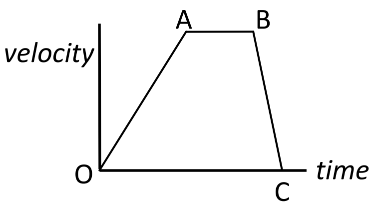
CD – at rest (zero velocity)

DE – constant acceleration in the opposite direction

EF – constant deceleration in the opposite direction

The acceleration of the object is equal to the gradient of the graph.

e.g.



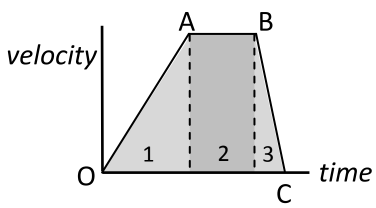

$$acceleration = gradient\ of\ graph$$

$$= \frac{change\ in\ velocity}{time}$$

Note: negative gradients represent negative accelerations

The displacement of the object is equal to the area under the graph.

e.g.




$$displacement = area\ under\ graph$$

$$= area\ 1 + area\ 2 + area\ 3$$

Note: areas under the velocity-time graphs represent negative displacements (displacements in the opposite direction)

**Dynamics**

# Forces

# Summary

Forces have the ability to change the shape, speed and direction of an object.

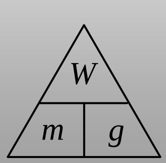
Force is measured in newtons (N).

Forces can be measured with a newton balance (or a spring balance or force-meter).

**Weight, Mass and gravitational field strength**

$$\underset{\text{N}}{weight} = \underset{\text{kg}}{mass} \times \overset{\text{N kg}^{-1}}{gravitational\ field\ strength}$$

$$W = mg$$




$$m = \frac{W}{g}$$

$$g = \frac{W}{m}$$

**Mass**, $m$, is the amount of matter in an object and is measured in kilograms (kg). The mass of an object is the same, no matter where it is in the Universe.

**Weight**, $W$, is the force of gravity on an object and is measured in newtons (N). The weight of an object depends on both its mass and the strength of gravity.

**Gravitational field strength**, $g$, is the weight per unit mass and is measured in newtons per kilogram (N $kg^{-1}$). The gravitational field strength is different at different places in the Universe. On Earth $g$ has a value of 9·8 N $kg^{-1}$. The value of $g$ decreases with distance from the planet's surface.

**Friction** is the force that opposes motion. Friction arises when surfaces rub together. When there is friction, heat is produced.

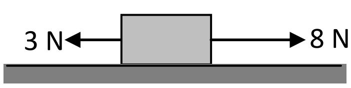
Situations in which friction is reduced include: lubricating a bicycle wheel with oil, using rollers on a conveyor belt, wearing swimsuits made of vey smooth materials and waxing skis.

Situations in which friction is increased include: pressing brake pads onto a bake disc, using chalk to absorb moisture when rock climbing, using rubber on car tyres to increase 'grip'.

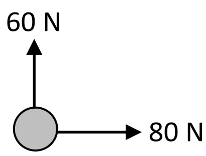
**Air resistance**, or drag, is a form of friction. Air resistance increases with speed. Air resistance can be reduced by **streamlining**.

Forces are vector quantities and therefore have both a magnitude (size) and direction.

e.g.




resultant force = 5 N right




resultant force = 100 N @ 54° to vertical

Equal forces acting in opposite directions are known as balanced forces. When the forces on an object are balanced the object remains at rest or continues to move at a constant speed in a straight line. This is known as **Newton's First Law of Motion** (Newton I)

When the forces on an object are unbalanced the object will accelerate. The acceleration of an object depends on the mass of the object and the size of the unbalanced force:

Acceleration is directly proportional to the unbalanced force on the object.

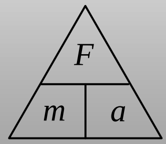
Acceleration is inversely proportional to the mass of the object.

The relationship between unbalanced force, mass and acceleration is known **as Newton's Second Law of Motion** (Newton II).

To accelerate an object upwards the lifting force must be greater than its weight, so there is an unbalanced upward force (e.g. rockets)

**Force, Mass and Acceleration**

$$\underbrace{\text{unbalanced force}}_{\mathrm{N}} = \underbrace{mass}_{\mathrm{kg}} \times \overbrace{acceleration}^{\mathrm{m\ s^{-2}}}$$




$$F = ma$$

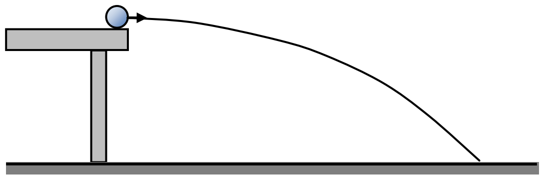
$$m = \frac{F}{a}$$

$$a = \frac{F}{m}$$

**Newton's Third Law of Motion** (Newton III) states "*For every action there is an equal and opposite reaction*." In practice, this means that if object A exerts a force on object B, then object B exerts an equal and opposite force back on object A. Such forces are known as 'newton pairs' (e.g. a rocket exerts a downward force on exhaust gases and the gases exert an equal and opposite force upwards on the rocket).

When an object is dropped it initially accelerates due to the force of gravity. As it travels faster air resistance increases, the unbalanced force decreases and the acceleration decreases. Eventually the weight and air resistance become balanced; at this point the object falls at a constant velocity known as its **terminal velocity**.

When an object is projected in a gravitational field (e.g. when a ball is thrown on Earth) it will follow a curved path. This is known as projectile motion.



Projectile motion because the only force acting on the object is the force of gravity (weight) acting vertically downwards. This results in a constant downward acceleration. Whereas there are no horizontal forces so the object continues to move with a constant horizontal velocity.

The horizontal and vertical motion of a projectile can be treated separately:

horizontal motion: area under $v_h$-$t$ graph (horizontal range)

$$v_h = \frac{s}{t} \quad \text{(constant horizontal velocity)}$$

vertical motion: area under $v_v$-$t$ graph (vertical height)

$$v_v = u_v + at \quad \text{(constant vertical acceleration)}$$

(Note: on Earth a = 9·8 m $s^{-2}$)

A satellite experiences an unbalanced downwards force due to its weight. This causes it to accelerate towards the Earth. However, its horizontal velocity sufficiently large that, as it accelerates toward the surface of the Earth, the surface ‘curves away’ from it and it follows a circular orbit.

# Energy

## Summary

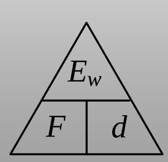
**Work done** is a measure of the energy transferred during an energy change.

Work done is measured in Joules (J).

The work done by a force on an object is equal to the force applied multiplied by the distance travelled.

**Work done, Force and Distance**

$$\underbrace{Work\ done}_{\text{J}} = \underbrace{force}_{\text{N}} \times \overbrace{distance}^{\text{m}}$$




$$E_w = Fd$$

$$F = \frac{E_w}{d}$$

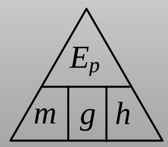
$$d = \frac{E_w}{F}$$

**Gravitational potential energy** is the energy associated with raising or lowering an object in a gravitational field

When an object is lifted the force applied to lift the object at constant speed is equal to its weight ($W=mg$) and the distance it travels is equal to the height, $h$. Therefore the work done in lifting the object is equal to $mg$ multiplied by $h$. This means the gain in gravitational potential energy is equal to $mgh$ ($E_p=mgh$).

**Gravitational Potential Energy**

$$\underbrace{gravitational\ potential\ energy}_{\text{J}} = \overbrace{mass}^{\text{kg}} \times \overbrace{gravitational\ field\ strength}^{\text{N kg}^{-1}} \times \underbrace{height}_{\text{m}}$$




(on Earth g = 9·8 N kg$^{-1}$)

$$E_p = mgh$$

$$m = \frac{E_p}{gh}$$

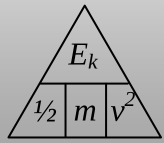
$$h = \frac{E_p}{mg}$$

**Kinetic energy** is the energy associated with a moving object.

The kinetic energy of a moving object depends on its mass, $m$, and speed, $v$.

**Kinetic Energy**

$$\overbrace{kinetic\ energy}^{\mathrm{J}} = ½ \times \underbrace{mass}_{\mathrm{kg}} \times \overbrace{speed}^{\mathrm{m\ s^{-1}}}{}^{2}$$




$$E_k = ½mv^2$$

$$m = \frac{E_k}{½v^2}$$

$$v = \sqrt{\frac{E_k}{½m}}$$

When energy is changed from one form to another the total amount of energy remains constant; in other words energy can neither be created nor destroyed. This is known as the **Principle of Conservation of Energy**.

Very often during energy transformations some energy appears to be “lost”, but this is because it is changed into heat due to friction or air resistance.

Examples of energy transformations include:

- car accelerating – chemical to kinetic (and heat) energy
- ball falling – gravitational potential to kinetic (and heat) energy
- bicycle braking – kinetic to heat energy