

# AQA GCSE Physics

## Topic 5: Forces

### Notes

(Content in bold is for Higher Tier only)



## Vectors

A Vector has magnitude and direction

A Scalar has just magnitude

- Generally, scalars cannot be negative, but vectors can be, as a certain direction is positive

### Examples

- Speed is scalar
- Velocity is vector
- Distance is scalar
- Displacement is vector
- Time is scalar
- Acceleration is vector
- Force is vector
- Mass is scalar
- Momentum is vector
- Energy is scalar

Imagine a ball thrown off a cliff, displacement is 0 at height of cliff, above the cliff the ball has positive displacement, and below the cliff top the ball has negative displacement.

- In long answer questions, you may be able to decide where the "0" point of a vector may lie, for example you could set zero to be bottom of cliff, so the ball will never have negative displacement
- Speed is only velocity when given a direction, so thrown  $10\text{ms}^{-1}$  is its speed but thrown  $10\text{ms}^{-1}$  at  $30^\circ$  above the horizontal is the velocity

**Imagine a car travelling round a roundabout at constant speed. While its speed is constant, its direction is constantly changing – so its velocity is constantly changing therefore it is accelerating.**

Vectors can be represented by arrows, with their size/length representing the vector magnitude

## Object Interaction

- A force is a push or pull that acts on an object due to the interaction with another object. All forces between objects are either:
  - Non-Contact - the objects are physically separated.
    - o Electrostatic
      - The charges cause a force of attraction/repulsion
    - o Gravitational attraction
      - The mass creates a force of attraction
  - Contact - the objects are physically touching
    - o Normal contact force, which is felt in opposite direction to contact
      - The force is normal to the planes of contact
    - o Friction
      - The surfaces and their roughness cause friction when moved in contact



## Gravity

All matter has a gravitational field, and attracts all other matter

- The larger the mass, the stronger the field, the greater the attraction

## Weight

- The force exerted on a mass by the gravitational field, in Newtons

weight = mass  $\times$  gravitational field strength

$$W = mg = m \times 10$$

Weight,  $W$ , in newtons,  $N$  and mass,  $m$ , in kilograms,  $kg$

- Measured by a force meter (also known as calibrated spring-balance)
  - o Weighing scale measures the force you exert, and then divides by 10 to give mass
- You need to recall that on earth,  $g = 9.8$

Same person, on two different planets?

- Their **mass is the same**
- The gravitational field strength,  $g$ , **at the two planets will be different** (i.e. not 10 for both)
  - o So their weight will be different on both

Acceleration in free fall is due to gravity, and is the same as  $g$ , i.e.  $10ms^{-2}$

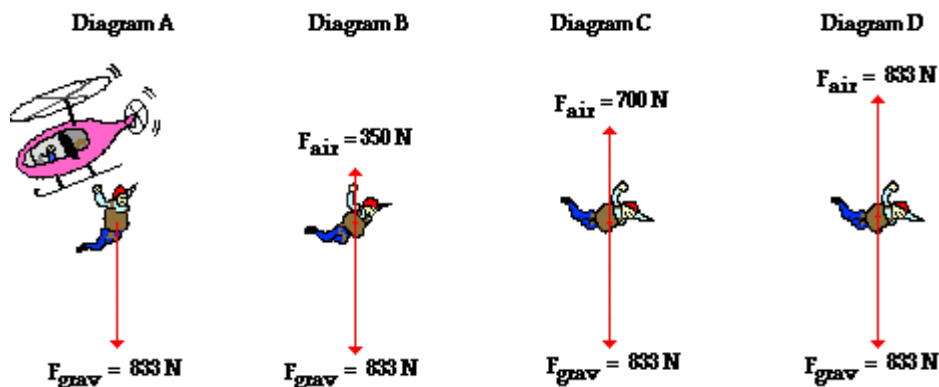
The weight of an object is considered to act at the object's centre of mass

## Resultant Force

- This is a single force representing the sum of all the forces acting on an object
- If more than one force act along a straight line, the resultant can be found by adding (acting in the same direction) or subtracting (acting in opposite directions) them

## Skydiver example

- Forces that act are air resistance and weight



<http://www.physicsclassroom.com/>

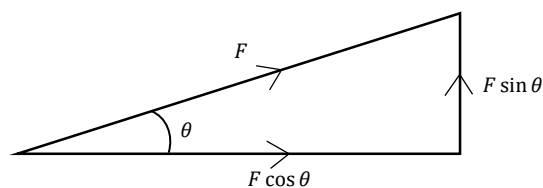
- Initially, the skydiver has no air resistance and the **only** force acting on him is weight



- As he falls, he accelerates, increasing his speed (A)
  - o Resultant is simply 833N down
- As air resistance increases, the *resultant* force from weight *decreases* (B)
  - o Resultant is  $833 - 350 = 483\text{N}$  down
- So acceleration decreases, so he is not speeding up as quickly (C)
  - o Resultant is 133N down
- Eventually they are equal and balance, so there is *no* resultant force (D)
  - o Resultant = 0
- So there is *no* acceleration when the resultant force is 0 they travel at terminal velocity.
- Free Body Diagrams show the forces (and their directions) acting on an object, like for the skydiver above

## Resolving Forces

- A force  $F$  at angle  $\theta$  to the ground can be resolved parallel and perpendicular to the ground
- Using Pythagoras' Rule, the two components are as shown



$$a^2 + b^2 = c^2$$

$$F^2 = (F \cos \theta)^2 + (F \sin \theta)^2$$

## Work

Work Done = Force  $\times$  Distance

$$W = Fs$$

- Where Work Done,  $W$ , is in joules  $J$ , the force,  $F$  is in newtons  $N$  and the distance,  $s$  is in metres  $m$ .
- Where distance is **distance moved along the line of action of the force**
- Work done is when energy is transferred from the object doing the work to another form
  - o If a book is lifted 1m in the air, and 2m to the right
  - o Work is done (against gravity) when moving 1m vertically, as that is in the direction of the force (gravity)
  - o Energy is transferred from your muscles to the book, increasing its gravitational potential.
- One joule of work is done when a force of one newton causes a displacement of one metre.  
1 joule = 1 newton-metre

**Work done against frictional forces causes a rise in temperature of the object**

## Springs

- To stretch, bend or compress an object, more than one force has to be applied
- If a single force is applied to an object, it will just move in that direction
  - o If it is pulled in opposite directions on either side of the object, it will stretch
  - o If it is fixed at one point and stretched, a force is still being applied by the fixed point

Deformation

- This means changing shape



- **Elastic Deformation**
  - o The object returns to its original shape when the load has been removed
  - o Elastic band
- **Plastic Deformation**
  - o The object does not return to its original shape when the load has been removed
  - o A spring when pulled too far

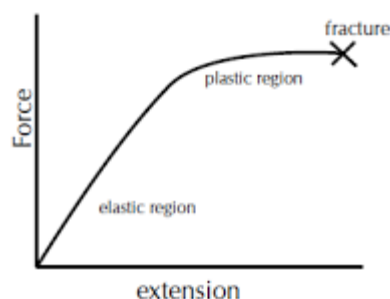
### Hooke's Law

The extension of an elastic object, such as a spring, is directly proportional to the force applied, provided that the limit of proportionality is not exceeded.

$$F = kx$$

where:

- F is the force applied to the spring,  $N$
  - K is the spring constant,  $Nm^{-1}$
  - X is the extension,  $m$
- Linear line for a Force/Extension Graph
    - This is elastic region
    - It is following Hooke's Law
    - Gradient is k
  - The point it stops being linear is the limit of proportionality.
    - From then on, it does not obey Hooke's Law
  - Non-Linear line
    - There is plastic behaviour here
    - It is not following Hooke's Law
    - If shallow
      - o Lots of extension for not a lot of force
      - o Easy to stretch



If graph is just linear, with no non-linear end section, the material is **brittle**, so snaps instead of stretches after the elastic limit

### Work Done

$$\text{Work Done} = \frac{1}{2}kx^2$$

- When a force stretches/compresses a spring, the spring does work
  - o Elastic potential energy is stored in the spring
  - o Provided it does not inelastically deform:
    - The work done on the spring = the elastic potential energy stored

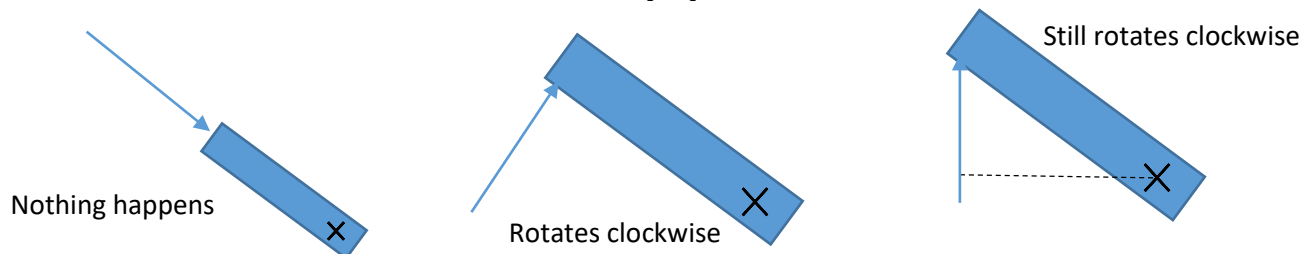
### Moments and Rotation (Physics only)

- For an object attached to a pivot point (a point which it can rotate about, but cannot move away from);
  - o If a force is applied along a line passing through the pivot (see diagram), the object does not rotate, and is just held still.



- If there is a distance between the pivot and the line of action of the force, the object rotates about the pivot, in the direction of the force applied.
- If the Force is applied not perpendicular to the object we need to consider the **perpendicular distance** from pivot to line of force

Moment of a Force = force  $\times$  perpendicular distance



$$M = Fd$$

where moment of a force,  $M$ , in newton-metres Nm, force  $F$  in newtons N and distance  $d$  is the perpendicular distance from the pivot to the line of action of the force, in metres m.

Example of moments: Bike Riding – pressing your foot down on the pedal, causes a moment about the pivot, turning the pedal arms.

Equilibrium is when: **sum of anticlockwise moments = sum of clockwise moments**

## Levers and Gears (Physics only)

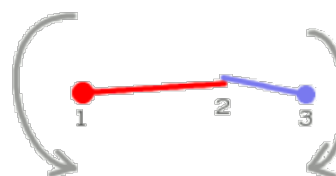
- Gears can change speed, force or direction by rotation

For an example when the first gear is supplying the force

- If connected to a gear with fewer teeth (i.e. a smaller gear)
  - The second gear will turn faster
  - But with less force
  - In opposite direction to first gear
- If connected to a gear with more teeth (i.e. a larger gear)
  - Turns slower
  - More force
  - In opposite direction

The **second gear will always turn in the opposite direction**

- Blue gear is supplying the power
- To increase the power, a larger gear is used for the secondary (red)
  - As the force on the red gear is a further distance from its pivot, the momentum of the larger gear is greater



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## Pressure (Physics only)

Particles in a gas move **randomly** in every direction and they exert forces on their container, which is felt as pressure.

$$\text{pressure, } p = \frac{\text{force}}{\text{area}} = \frac{F}{A}$$

Where the pressure,  $p$ , is in pascals Pa, the force,  $F$ , in newtons N and the area,  $A$ , in metres squared,  $\text{m}^2$ .

- Remember, pressure produces a net force at right angles to any surface

## Pressure in a Fluid (Physics only)

### Factors that influence floating and sinking

An object floats if its weight is less than the weight of the water it displaces

- So a 1000kg boat will sink into the water until it has displaced 1000kg of water
  - o Providing the boat doesn't completely submerge before it displaces this amount, then it will float.

Pressure in a liquid varies with depth and density, and this leads to an upwards force on a partially submerged object.

- The buoyancy force is the upwards force that counteracts the weight of the floating object
- This is equal to the weight of the fluid displaced by the object

A ping pong ball floats on water as its density is less than the density of the water, so for the volume displaced, the weight of the equivalent amount of water is greater than the weight of the ping pong ball, so the resultant force is buoyancy, so it floats

Increasing the depth, the greater the weight of the water above you, so greater force felt, so greater pressure

**pressure due to a column of liquid = height of column  $\times$  density of liquid  $\times$   $g$**

$$p = h\rho g$$

Where pressure  $p$  is in pascals Pa, the height of the column  $h$  in metres m, the density  $\rho$  in kilograms per metre cubed  $\text{kg}/\text{m}^3$  and the gravitational field strength  $g$  is in newtons per kilogram N/kg which is normally 10.

- **Upthrust:** A partially (or totally) submerged object experiences a greater pressure on the bottom surface than on the top surface. This creates a resultant force upwards which is known as upthrust.
- Earth's Atmosphere: A thin layer (relative to size of the earth) of air around the Earth.
  - o The atmosphere gets less dense with increasing altitude
- The atmosphere is a thin layer (relative to the size of the Earth) of air round the Earth. The atmosphere gets less dense with increasing altitude.



- This is because it is the total weight of the air above a unit area at a certain altitude.
  - o The weight of the air is the force which causes the pressure
  - o So with higher elevation, there are fewer air molecules above the unit area than the same area at lower heights, so there is a smaller weight, so less pressure

Idealised Assumptions, for a simple model of the atmosphere:

- Isothermal, so it is all at the same temperature
- Transparent to solar radiation
- Opaque to terrestrial radiation

## Force and Motion

**Distance** is how far an object moves. Distance does not involve direction. Distance is a scalar quantity.

**Displacement** includes both the distance an object moves, measured in a straight line from the start point to the finish point and the direction of that straight line. Displacement is a vector quantity.

**Speed** does not involve direction. Speed is a scalar quantity.

**Velocity**, which is a vector quantity, is speed in a given direction.

**If an object was travelling in a circular motion, the object is constantly changing direction, therefore the velocity, which is a vector that depends on the movement and the direction, is constantly changing. A change in velocity is defined as acceleration, so although the object isn't speeding up, it is accelerating due to the changing direction.**

The speed of a moving object is rarely constant. When people walk, run or travel in a car their speed is constantly changing.

Typical Speeds:

- Wind	-	$5 - 7ms^{-1}$	- Cycling	-	$\sim 6ms^{-1}$
- Sound	-	$330ms^{-1}$	- Bus	-	14km/h
- Walking	-	$\sim 1.5ms^{-1}$	- Train	-	125miles/h
- Running	-	$\sim 3ms^{-1}$	- Plane	-	900km/h

Distance measured in mm, cm, m and km and time measured in ms, s, mins and hours.

- Depending on lengths involved, use appropriate units

$$\text{speed} = \frac{\text{distance}}{\text{time}} \quad v = \frac{d}{t}$$

Remember to convert units to make sure everything is equivalent!

Average speed for non-uniform motion:

- Work out TOTAL TIME and TOTAL DISTANCE
- Then use:

$$\text{average speed} = \frac{\text{total distance}}{\text{total time}}$$

- E.g. 3 sections of different speeds to travel distances, use  $\text{time} = \frac{\text{distance}}{\text{speed}}$  to work out total time, then sum the different distances, then use above.

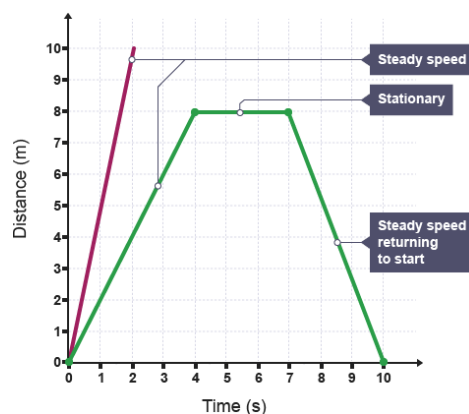




## Graphs

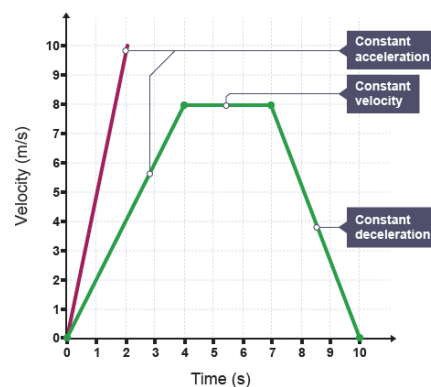
### Displacement-Time Graphs

- **Gradient is velocity**
- Sharper gradient means faster speed
- Negative gradient is returning back to starting point
- Horizontal line means stationary
- 0 Distance means that it is back to starting point
- Area under line = nothing
- Curved Line means that the velocity is changing (acceleration)
- **If an object is accelerating, its speed can be determined by drawing a tangent and calculating the gradient of the distance-time graph.**



### Velocity-Time Graphs

- **Gradient is acceleration**
- Sharper gradient means greater acceleration
- Negative gradient is deceleration
- Horizontal line means constant speed
- 0 Velocity means that it is stationary
- **Area under line = distance travelled**
  - o Sometimes counting the squares is the best method for a curved line
- Curved Line means that the acceleration is changing

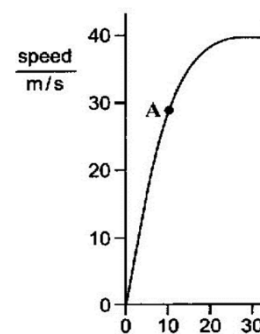


### Average Speed?

- This is for when the speed changes during the motion
- Use overall distances and timings to work out average speed

### Falling in a fluid (Physics only)

- Initially, the object will fall freely under gravity ( $9.8 \text{ m/s}^2$ )
  - o However drag forces will act (see skydiver)
  - o And then the object will move at terminal velocity
- The graph shows an initial steep gradient, which dies off to a flat gradient – acceleration decreases as drag increases, until no acceleration at terminal velocity,  $\sim 40 \text{ m/s}^{-1}$  in this case



<http://tankimia.blogspot.co.uk>

## Equations

$$\text{Average Speed} = \frac{\text{Total Distance}}{\text{Total Time}}$$

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

$$v^2 = u^2 + 2as$$

$$\text{Kinetic Energy} = \frac{1}{2}mv^2$$



## Newton's First Law

An object has a constant velocity unless acted on by a resultant force

- If a resultant force acts on the object, it will accelerate
  - o Acceleration is change in velocity over time
  - o So the velocity will change
  - o Either the direction or speed of the object will change (or both)
- If no resultant force acts on the object
  - o And the object is stationary, it will remain stationary
  - o And the object is moving, it will continue to move at the same velocity

The tendency for objects to continue in uniform velocity (or stay at rest) is inertia

## Newton's Second Law

The acceleration of an object is proportional to the resultant force acting on the object, and inversely proportional to the mass of the object.

$$\text{Force} = \text{mass} \times \text{acceleration}$$

$$F = ma$$

where F is the force in newtons N, m is the mass in kg and a is the acceleration in m/s<sup>2</sup>.

## Inertia

- The measure of how difficult it is to change the velocity of an object

$$\text{inertial mass} = \frac{\text{force}}{\text{acceleration}} = \frac{f}{a}$$

## Newton's Third Law

Whenever two objects interact, the forces they exert on each other are equal and opposite.

- Rocket taking off
  - o The rocket exerts a force on the gases being ejected. The gases apply a force equal in magnitude but in opposite direction on the rocket, which lifts it off the surface.
- A book on a table
  - o The weight of the book (from the Earth) = the pull of the book on the Earth

## Vehicle Stopping Distances

- After seeing a hazard
  - o Before you react, during reaction time you travel X metres
    - Thinking Distance
  - o Then you react, causing the car to slow down and stop over Y metres
    - Braking Distance

stopping distance = thinking + braking distances

### Thinking Distance

- Speed
- Affected by reaction time
- Concentration
- Tiredness
- Distractions
- Influence of drugs/alcohol

### Braking Distance

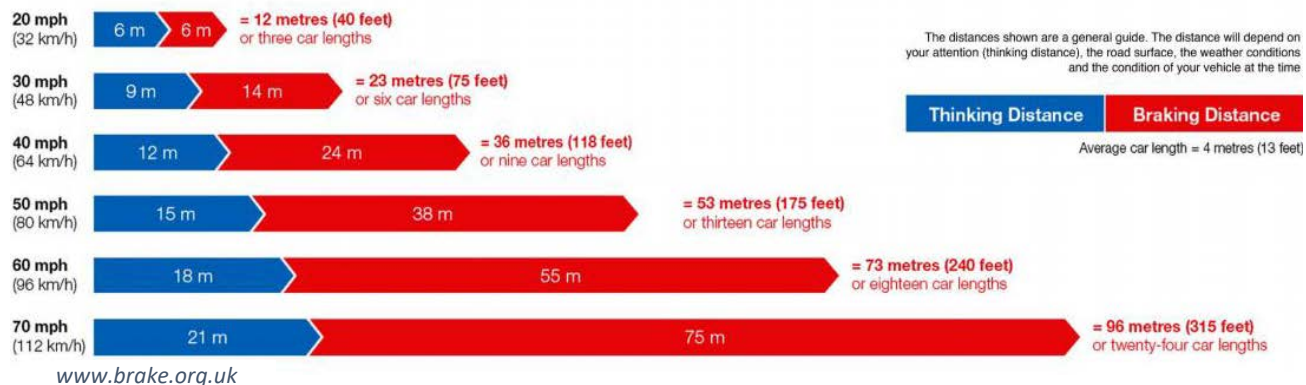
- Speed
- Poor road conditions (icy, wet)
- Bald tires (low friction)
- Worn brake pads
- Weight (more passengers)



## Speed and Braking Distance

- Greater the speed, the greater distance travelled during the same time (reaction time)

Typical stopping distances (Physics only):



Reaction Times vary 0.2 – 0.9s for each person

- Measure reaction times by the “ruler drop”
  - o Drop a ruler through the person’s open hand, the time it takes to catch it can be determined by  $s = ut + \frac{1}{2}at^2$  where  $u = 0$  and  $a = g$ , so  $t = \sqrt{2gs}$ 
    - Where s is the distance the ruler travels through the hand

When a force is applied to the brakes of a vehicle:

- Work is done by the brakes (by friction) onto the wheel
  - o So the vehicle’s KE reduces
  - o And the temperature of the brakes increase
- Greater the speed = greater braking force needed to stop the car (over the same distance)
  - o So greater force = greater acceleration
  - o This may lead to brakes overheating and a loss of control, which is dangerous

## Momentum

$$\text{momentum} = \text{mass} \times \text{velocity}$$

$$p = mv$$

Where p is the momentum in kilograms metres per second  $\text{kgms}^{-1}$ , m is the mass in kilograms kg and v the velocity metres per second  $\text{ms}^{-1}$ .

- **Momentum is always conserved in a collision or explosion** (where there are no external forces like friction, air resistance, electrostatic attraction etc.)
- In collisions:
 
$$\text{total momentum before} = \text{total momentum after}$$
- So two marbles colliding, each will have momentum before and after the collision
  - o Remember momentum is a vector



## Changes in Momentum (Physics only)

**Newton's Second Law: Force is equal to the rate of change of momentum**

$$\text{Force} = \frac{\text{change in momentum}}{\text{time}} = \frac{(mv - mu)}{t}$$

### Safety Features (Physics only)

- **When braking hard, there is a large deceleration**
- **So a large force is felt on the passengers and the cars**
- **This can be dangerous, as the force felt can cause injury (neck whiplash etc.)**
  - **This can be explained by the equation above – large deceleration = large change in momentum over a short time, so a large force exerted on the object (person!)**
- **Safety**
  - **Seatbelts**
    - **Without these, when hard braking you will keep moving and not decelerate, causing to fly through the windshield**
    - **These strap you in, but also stretch under large forces**
    - **Stretching increases the distance moved slightly, but extends the time taken more for passengers to stop**
    - **This decreases the rate of change of momentum and therefore reduces the force**
  - **Crumple zones**
    - **Without these, the car would be a solid metal block, which would immediately stop during a crash instead of “softening” the blow slightly**
    - **“softer” areas at the front of the car, which crumple upon a crash**
    - **It absorbs energy to deform and compact**
    - **It increases the time taken for the car to stop**
    - **This reduces acceleration and force on passengers**
  - **Air Bags**
    - **Without these your head will whip forward during a crash, hitting the steering wheel or whipping back to hit the back of the head, which would cause serious neck injury**
    - **These inflate instantaneously upon a crash**
    - **Your head hits this and slows down**
    - **Increases the time taken for the head to stop moving**
    - **So reduces the force on the neck**

