

AQA GCSE Physics — Physics

Topic 5

Forces

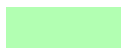
Specification 8463 · AQA

Free edition

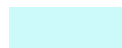
Revision notes for one topic, free to download.

These are the summary notes only. The full edition of this booklet also carries the worked examples, the required practicals and the formula sheets, with every topic in one place.

Colour Codes



Definitions



Diagrams



Notes and warnings



Sub-topic headings

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Define Scalar quantity

- has magnitude only.

Define Force

- a push or pull acting on an object due to the interaction with another object.

Define Centre of mass

- the single point at which an object's weight may be considered to act.

Define Work done

- the energy transferred when a force moves an object through a distance.

Define Inelastic deformation

- the object does not return to its original shape.

Define Spring constant

- force needed per metre of extension; a measure of stiffness.

Define Moment of a force

- the turning effect of a force about a pivot. **PHYSICS ONLY**

Define Pressure

- the force acting normal (at right angles) to a surface, per unit area of that surface.

Define Displacement

- distance in a straight line from start to finish, plus direction; a vector.

Define Vector quantity

- has magnitude and an associated direction.

Define Contact / non-contact force

- objects touching / physically separated.

Define Weight

- the force acting on an object due to gravity.

Define Resultant force

- the single force with the same effect as all the original forces.

Define Elastic deformation

- the object returns to its original shape when the force is removed.

Define Limit of proportionality

- the point beyond which extension stops being proportional to force.

Define Fluid

- a liquid or a gas. **PHYSICS ONLY**

Define Upthrust

- the resultant upward force on a submerged object. **PHYSICS ONLY**

Define Atmospheric pressure

- the pressure created by air molecules colliding with a surface.

Define Velocity

- speed in a given direction; a vector.

HIGHER TIER

Define Inertia

- the tendency of objects to continue in their state of rest or of uniform motion. **HT ONLY**

Define Terminal velocity

- the constant velocity of a falling object once the resultant force is zero.

Define Stopping distance

- thinking distance + braking distance.

HIGHER TIER

Define Momentum

- mass $\times$ velocity. **HT ONLY**

5.1 Forces and their interactions

5.1.1 Scalar and vector quantities

- **Scalar** quantities have **magnitude only**; **vector** quantities have **magnitude and an associated direction**.
- A vector may be shown by an **arrow**: its **length** gives the magnitude, its **direction** the direction.

Scalars	Vectors
distance, speed	displacement, velocity
mass, energy, time	weight and all other forces
temperature	acceleration, momentum

5.1.3 Gravity

- **Weight** is the force acting on an object due to **gravity**; gravity close to the Earth is due to the **gravitational field** around the Earth.
- Weight depends on the gravitational field strength at the point where the object is ($g \approx 9.8 \text{ N/kg}$ on Earth, $\approx 1.6 \text{ N/kg}$ on the Moon) and acts at the **centre of mass**.
- Measured with a **calibrated spring-balance** (a **newtonmeter**); weight $\propto$ mass.

5.1.2 Contact and non-contact forces

- A **force** is a push or pull acting on an object due to the interaction with another object. Force is a vector, in newtons (N).
- **Contact forces** (objects touching): friction, air resistance, tension, normal contact force.
- **Non-contact forces** (objects separated): **gravitational, electrostatic, magnetic**.
- Describe the **interaction between pairs of objects** as vectors: the Earth pulls the Moon, and the Moon pulls the Earth equally the opposite way.

WATCH OUT

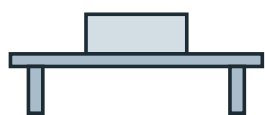
Mass and weight are different. Mass is a scalar in **kilograms**, the same everywhere. Weight is a force, a vector, in **newtons**, and depends on g . A 60 kg astronaut still has 60 kg of mass on the Moon but weighs about 96 N there, not 590 N. Never write "weight = 60 kg".

5.1.4 Resultant forces

- Several forces may be replaced by a **single force with the same effect** — the **resultant force**. In a straight line, add forces acting the same way and subtract those acting the opposite way.
- HT ONLY** Describe the forces on an **isolated object or system**, and use **free body diagrams** where several forces give a resultant — including balanced forces, where the resultant is zero. Draw the object as a dot or box with one arrow per force acting **on** it, arrow length proportional to force.
- HT ONLY** A single force can be resolved into two components at right angles; together they have the **same effect** as the single force.
- HT ONLY** Use **scale vector diagrams** for resolution of forces and equilibrium, and to find the resultant of two forces, giving **magnitude and direction** (scale drawings only).

Free body diagrams for a book on a table and a car at steady speed

Book on a table



normal contact force
from the table 10 N



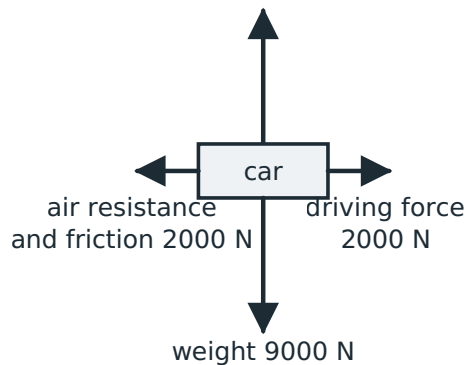
weight 10 N

Resultant force = 0 N
forces balanced

Car at a steady speed



normal contact force
from the road 9000 N



air resistance
and friction 2000 N

driving force
2000 N

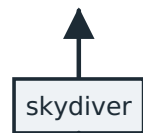
weight 9000 N

Resultant force = 0 N
balanced — constant velocity

Falling skydiver



air resistance 400 N



weight 700 N

Resultant force = 300 N
downwards — speeds up

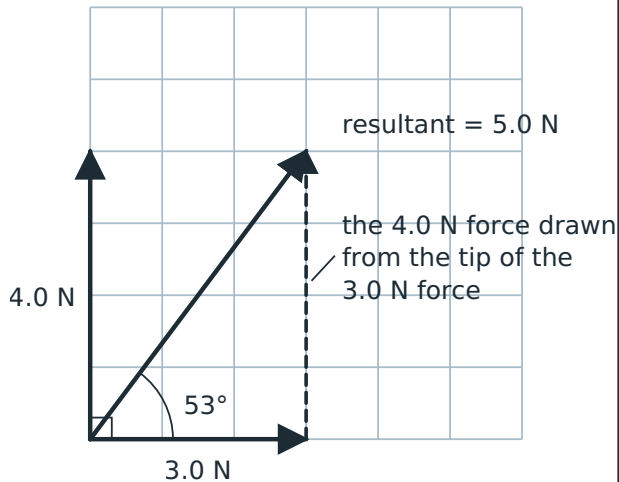
The length of each arrow shows the size of the force. A longer arrow means a bigger force.

WATCH OUT

A resultant force is needed to **change** motion, not to **maintain** it. "It's moving, so there must be a forward force" is wrong: an object at **steady velocity** has **zero** resultant force. A resultant force is only needed to speed up, slow down or change direction.

Higher tier only

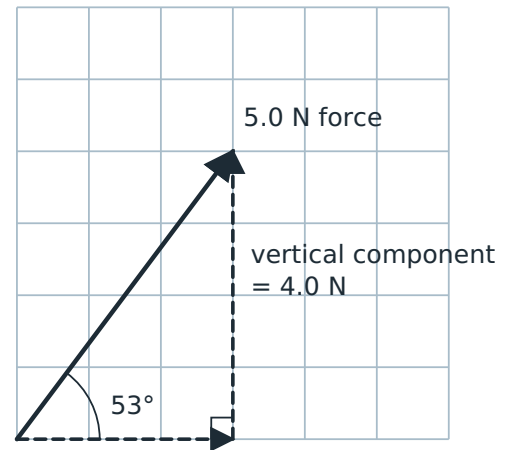
Adding two forces at right angles



Scale: 1 square = 1.0 N

Measure the length and the angle on the drawing.

Resolving one force into components



horizontal component = 3.0 N

The two components together have the same effect as the single force.

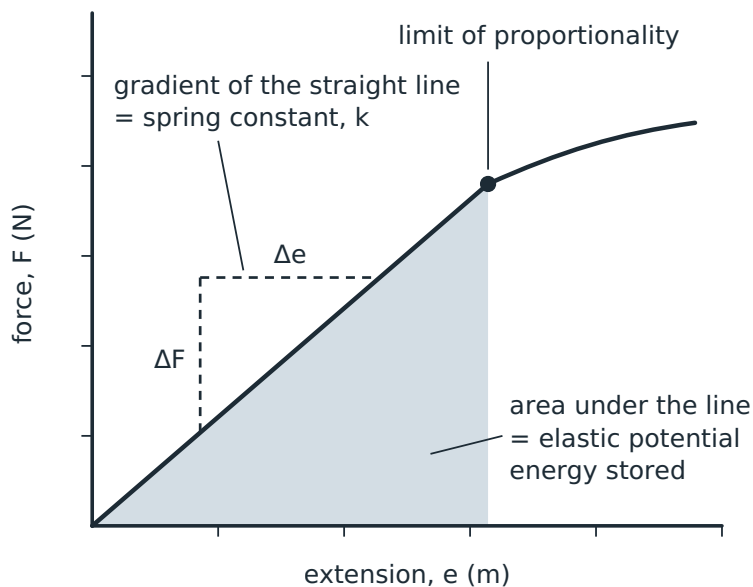
5.2 Work done and energy transfer

- When a force causes an object to move through a distance, work is done on it — a force does work when it causes a **displacement**.
- Work done **is an energy transfer**: lifting a box transfers energy to its gravitational potential energy store.
- One joule of work is done when a force of one newton causes a displacement of one metre: **1 J = 1 Nm**, so 250 Nm = 250 J.
- **Work done against the frictional forces acting on an object causes a rise in the temperature of the object** — energy goes to thermal stores. Hence warm hands when rubbed, and hot brakes.

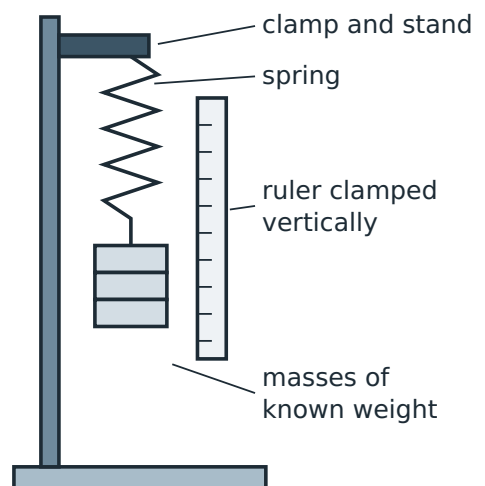
5.3 Forces and elasticity

- Forces in deformation: **tension** in a stretching bungee cord, **compression** in car suspension springs, the forces bending a diving board.
- To change the shape of a **stationary** object by **stretching, bending or compressing**, more than one force must be applied — one force alone would just accelerate it. A spring must be pulled at both ends, or pulled and held.
- **Elastic deformation** — the object **returns** to its original shape when the forces are removed. **Inelastic deformation** — it **does not return**.
- The extension of an elastic object is directly proportional to the force applied, provided the limit of proportionality is not exceeded. The same applies to compression, where e is the compression.
- **Extension = stretched length – original length**. Always subtract before plotting.
- **Force–extension graph** (force on y , extension on x): the **linear** part is a straight line through the origin whose **gradient = the spring constant k** ; a stiffer spring gives a steeper line. Past the **limit of proportionality** the line curves and the relationship becomes **non-linear**.

A force–extension graph, and the apparatus for required practical 6



Required practical 6



- extension = stretched length – original (unstretched) length
- force is directly proportional to extension up to the limit of proportionality: $F = k e$
- gradient of the straight line = spring constant, k (in N/m)
- area under the line = elastic potential energy stored: $E_e = \frac{1}{2} k e^2$ (given on the equation sheet)

- A force that stretches or compresses a spring does work, and elastic potential energy is stored in the spring. Provided the spring is not inelastically deformed, the work done on the spring and the elastic potential energy stored are equal.

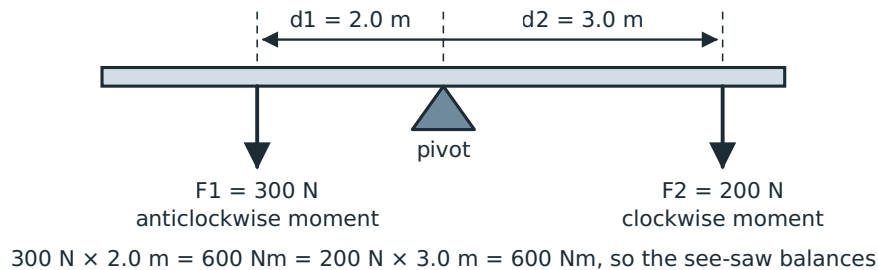
5.4 Moments, levers and gears PHYSICS ONLY

- **PHYSICS ONLY** A force or system of forces may cause an object to **rotate** — a door on its hinges, a spanner on a nut, a see-saw. The turning effect is the **moment of the force**.
- **PHYSICS ONLY** If an object is balanced, the total clockwise moment about a pivot equals the total anticlockwise moment about that pivot. Use this to find an unknown force or distance from the pivot. **PHYSICS ONLY Levers** transmit the rotational effect of a force: the effort acts far from the pivot and the load close to it, so a small effort gives a large force on the load. **PHYSICS ONLY Gears** are toothed wheels that transmit the rotational effect of forces. The force at the teeth is the same for both, so a larger gear turns with a larger moment but more slowly; a large gear driving a small one gives a **smaller moment but higher speed**. Interlocking gears turn **opposite ways**.

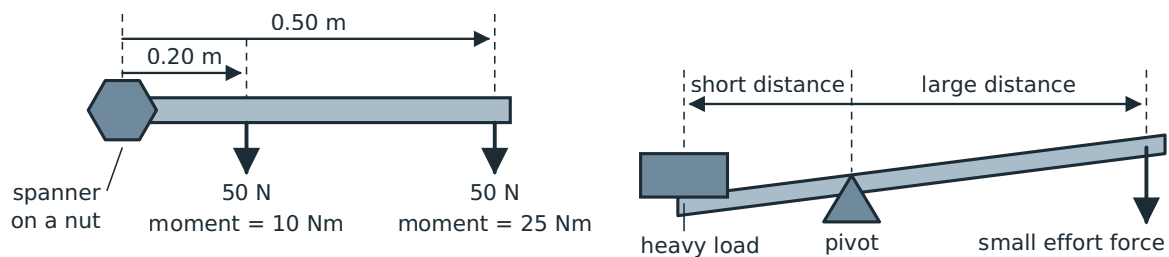
Balanced see-saw — the principle of moments

moment of a force, $M = \text{force, } F \times \text{perpendicular distance from the pivot, } d$ (in Nm)

When it is balanced: total clockwise moment = total anticlockwise moment

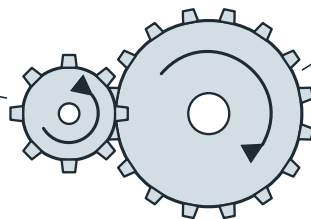


Levers — the same force at a greater distance gives a bigger moment



Gears — a larger gear turns more slowly with a greater moment

small gear —
turns quickly,
smaller moment



large gear — it has more teeth,
so it turns more slowly.

Its greater radius means a greater
distance from the centre, so the same
force at the teeth gives a greater moment ($M = F d$).
Linked teeth: the gears turn in opposite directions.

5.5.1 Pressure in a fluid

5.5.1.1 Pressure in a fluid 1

- **PHYSICS ONLY** A **fluid** can be a **liquid or a gas**. The pressure in fluids causes a force normal (at right angles) to any surface.
- **PHYSICS ONLY** For a given force a **smaller area gives a greater pressure** — hence sharp drawing pins and wide skis.

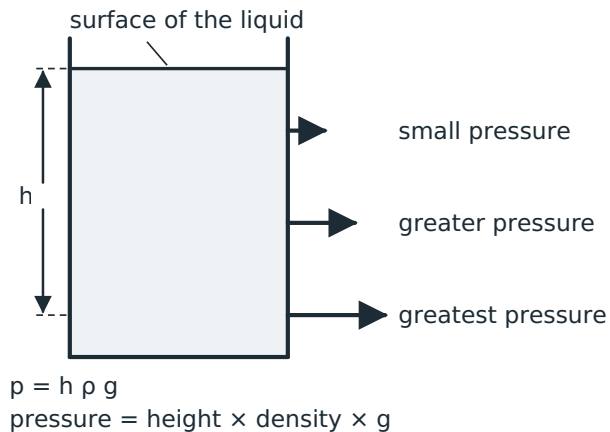
5.5.1.2 Pressure in a fluid 2 **PHYSICS ONLY**

HT ONLY

- **PHYSICS ONLY HT ONLY** Pressure at a point in a liquid increases with the height of the column of liquid above that point (more liquid above, so a greater weight pressing down) and **with the density of the liquid** (more mass, so more weight, in the same volume). For a **pressure difference between two depths**, work out p at each depth and subtract.
- **PHYSICS ONLY HT ONLY** A partially or totally submerged object has a greater pressure on its bottom surface than on its top surface, giving a **resultant force upwards** — the **upthrust**. **PHYSICS ONLY HT ONLY Floating and sinking:** it **floats** if the upthrust equals its weight and **sinks** if its weight exceeds the largest possible upthrust. An object less dense than the fluid floats, because it displaces enough fluid to balance its weight before it is fully submerged.

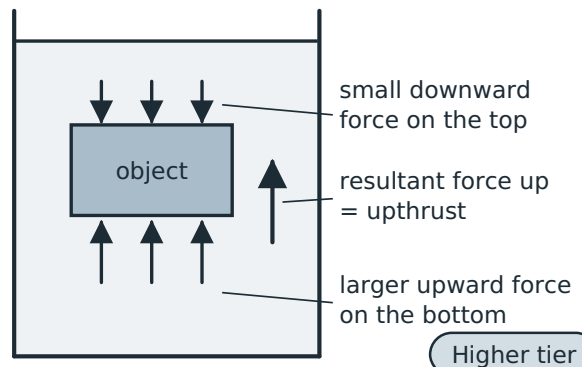
Physics only

Pressure increases with depth Higher tier



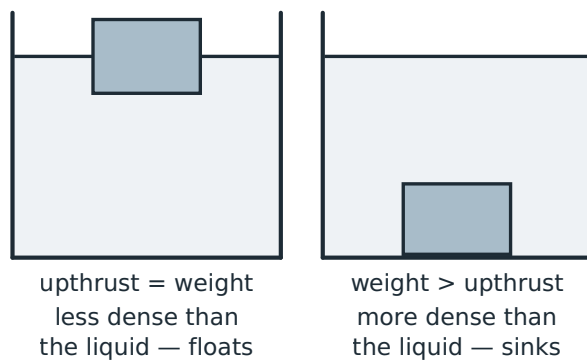
Upthrust on a submerged object

The pressure is greater on the bottom surface than on the top surface.



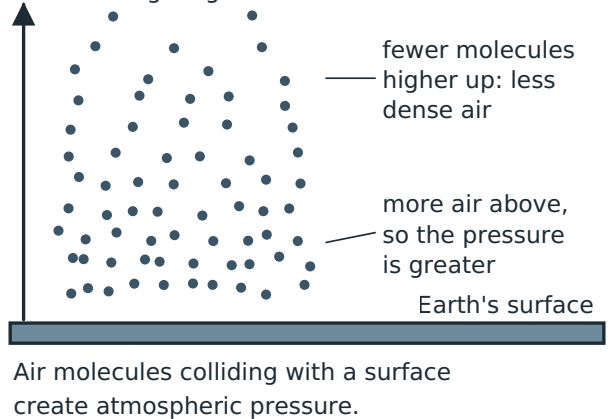
Floating and sinking Higher tier

Compare the density of the object with the density of the liquid.



Atmospheric pressure

increasing height



HIGHER TIER

HT ONLY Pressure increasing with depth in a liquid, and upthrust on a submerged object

5.5.2 Atmospheric pressure

- **PHYSICS ONLY** The **atmosphere** is a thin layer of air round the Earth (thin relative to the Earth's size) that gets **less dense with increasing altitude**. Air molecules colliding with a surface create atmospheric pressure.
- **PHYSICS ONLY** The number of air molecules, and so the weight of air above a surface, decreases as the height of the surface above ground level increases — there is always less air above a higher surface — so **atmospheric pressure decreases with height**.

5.6 Forces and motion

5.6.1 Describing motion along a line

5.6.1.1 Distance and displacement

- **Distance** is how far an object moves; it does not involve direction — a **scalar**.
- **Displacement** is the distance moved in a straight line from the start point to the finish point, plus the **direction** of that line — a **vector**. Give magnitude *and* direction, e.g. "5 km due north". A runner doing one lap of a 400 m track covers 400 m but has **zero displacement**.

5.6.1.2 Speed

- **Speed does not involve direction — speed is a scalar.**
- Speed is **rarely constant**: when people walk, run or travel in a car their speed changes constantly, so use average speed = total distance ÷ total time.
- How fast a person walks, runs or cycles depends on **age, terrain, fitness and distance travelled**. The **speed of sound** and the **speed of the wind** also vary.

Motion	Typical speed
Walking	~1.5 m/s
Running	~3 m/s
Cycling	~6 m/s
Car	~25 m/s
Train	~55 m/s
Aeroplane	~250 m/s
Sound in air	~330 m/s

HIGHER TIER

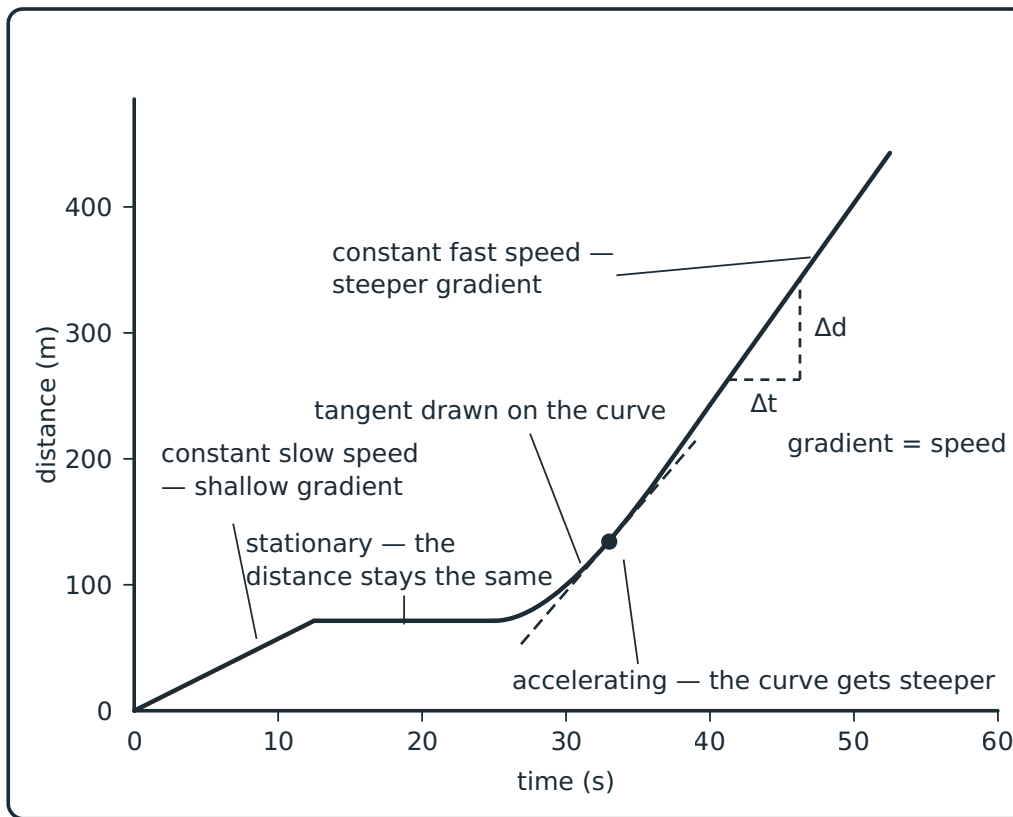
5.6.1.3 Velocity

- **Velocity is speed in a given direction** — a vector. Two cars at 20 m/s in opposite directions have the same **speed**, different **velocities**.
- **HT ONLY** Motion in a circle involves constant speed but changing velocity, because the direction changes continuously — a car on a roundabout at a steady 10 m/s is accelerating.

5.6.1.4 The distance–time relationship

- For motion in a straight line, distance is shown on a **distance–time graph** and **speed = the gradient**. A **horizontal line** means **stationary**, a **steeper line** a **greater speed**, a **curve** a changing speed.
- **HT ONLY** For an **accelerating** object, find the speed at a given time by **drawing a tangent** to the curve there and **measuring its gradient**.

Reading speed from a distance–time graph



How to read it

- flat line = stationary
- steeper line = faster
- gradient = speed
- speed = distance $\div$ time
- a curved line means the speed is changing
- to find the speed at an instant on a curve, draw a tangent and find its gradient

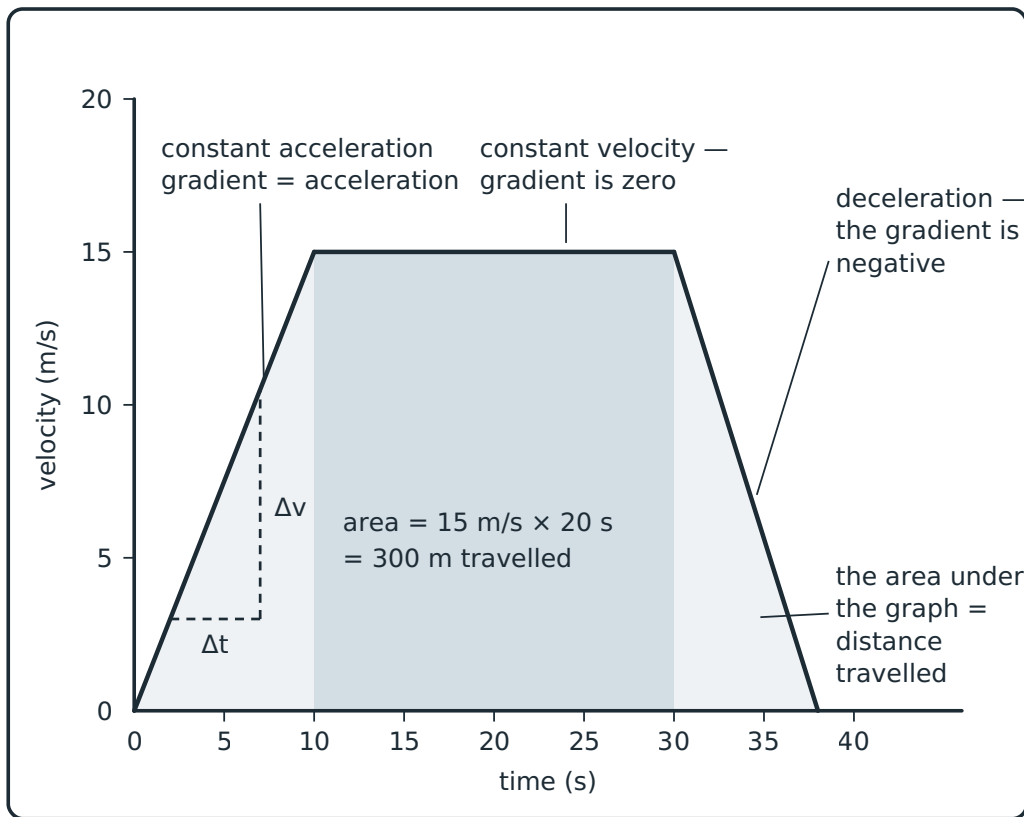
Higher tier only

HIGHER TIER

5.6.1.5 Acceleration

- An object that **slows down is decelerating** (negative acceleration).
- Acceleration = the gradient of a velocity–time graph; a horizontal line means zero acceleration.
- **HT ONLY** The distance travelled (or displacement) = the area under a velocity–time graph. Split it into triangles and rectangles, or **count squares** under a curve.
- Near the Earth's surface, any object falling freely under gravity has an acceleration of about 9.8 m/s^2 .
- Estimating everyday accelerations: a car reaching 13 m/s in 6 s gives $a \approx 2 \text{ m/s}^2$.

A velocity–time graph: gradient gives acceleration, area gives distance



How to read it

- gradient = acceleration
- flat line = constant velocity
- downward slope = deceleration
- area under the graph = distance travelled

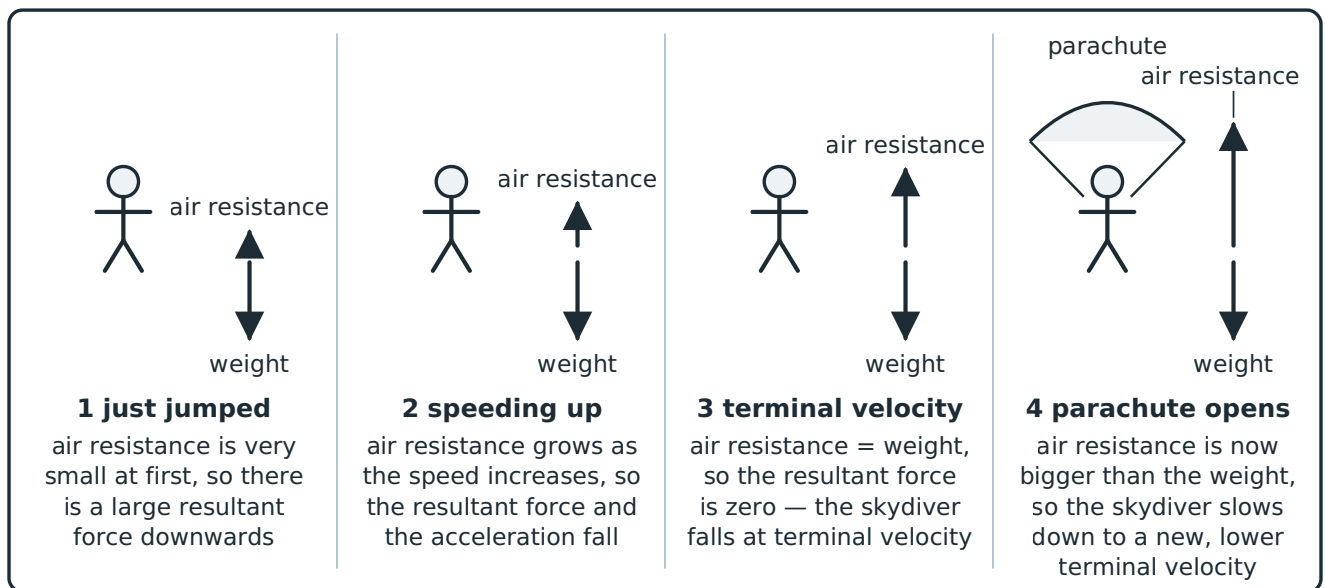
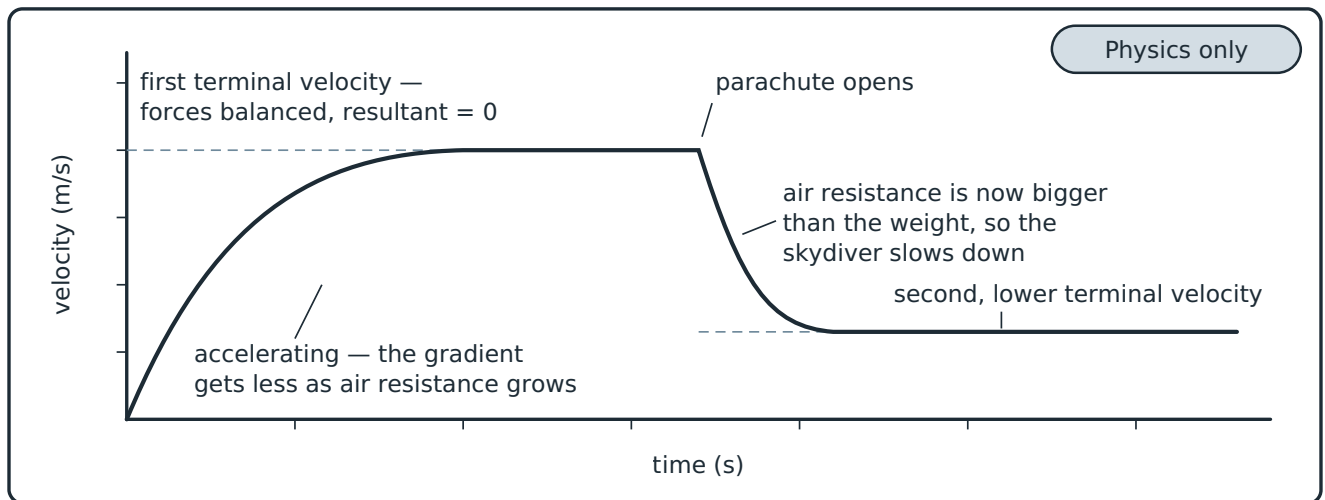
Higher tier only

- split the area into triangles and rectangles, or count squares

Terminal velocity

- An object falling through a fluid initially accelerates due to the force of gravity. As it speeds up **drag increases**, so the resultant force and acceleration fall. Eventually the resultant force will be zero — drag balances weight — and the object **moves at its terminal velocity**.
- **PHYSICS ONLY** On a **velocity–time graph** the line starts steep, becomes less steep, then levels off at the terminal velocity. When a parachute opens, drag exceeds weight, so the skydiver **decelerates** to a new, lower terminal velocity.

Reaching terminal velocity: how the forces on a falling object change



ANALOGY

Terminal velocity — sprinting into a headwind. The faster you run, the harder the air pushes back, until the push-back matches your maximum push forward and you cannot speed up. A skydiver is the same: weight is constant while drag grows with speed until the two balance.

ANALOGY

Inertia — the bus passenger. When the bus pulls away you lurch backwards; when it brakes you lurch forwards. Your body keeps doing what it was already doing, because nothing acted directly on you to change it — and a heavier passenger is harder still to get moving or to stop.

HIGHER TIER

5.6.2 Forces, accelerations and Newton's Laws of motion

5.6.2.1 Newton's First Law

- If the resultant force on an object is zero: a stationary object **remains stationary**; a **moving** object continues at the same speed and in the same direction, i.e. the same velocity.
- So when a vehicle travels at a steady speed the resistive forces balance the driving force, and the velocity of an object will only change if a resultant force acts on it.
- **HT ONLY** The tendency of objects to continue in their state of rest or of uniform motion is called **inertia**.

5.6.2.2 Newton's Second Law

- The acceleration of an object is proportional to the resultant force acting on it and inversely proportional to its mass: $a \propto F$ and $a \propto 1 \div m$.

HT ONLY **Inertial mass** measures how difficult it is to change the velocity of an object, and is defined as the ratio of force over acceleration ($m = F \div a$).

- Estimating for road transport: a ~1200 kg car accelerating at ~2 m/s² needs ~2400 N; emergency stops involve much larger accelerations and forces.

5.6.2.3 Newton's Third Law

- Whenever two objects interact, the forces they exert on each other are **equal and opposite**.
- In **equilibrium situations**: a book pushes down on a table and the table pushes up on the book equally; a swimmer pushes water backwards and the water pushes the swimmer forwards.

ANALOGY

Newton's Third Law — you can't push without being pushed back. Stand on a skateboard and push a wall: the wall pushes you back just as hard and you roll away. The two forces act on **different objects** — one on the wall, one on you — which is why they never cancel.

WATCH OUT

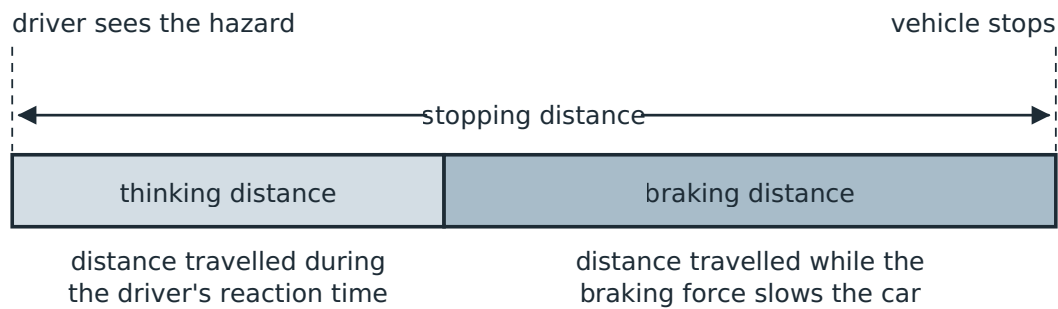
Third-law pairs act on different objects, so they never cancel. "The forces are equal and opposite, so nothing can accelerate" is wrong: the pair is the force **A exerts on B** and the force **B exerts on A**, and only forces on the **same** object combine into a resultant. A book's weight and the table's normal contact force are **not** a third-law pair — same object, different types of force; they are balanced only because the book is in equilibrium.

5.6.3 Forces and braking

5.6.3.1 Stopping distance

- Stopping distance** = thinking distance + braking distance, where **thinking distance** is the distance travelled during the driver's **reaction time** and **braking distance** is the distance travelled **under the braking force**.
- For a given braking force, the greater the speed of the vehicle, the greater the stopping distance. Thinking distance $\propto$ speed; braking distance grows much faster (roughly with speed squared, since $v^2 - u^2 = 2as$).
- PHYSICS ONLY** Be able to estimate the emergency stopping distance over a range of speeds typical for that vehicle and interpret graphs relating speed to stopping distance for a range of vehicles.

Stopping distance = thinking distance + braking distance



stopping distance = thinking distance + braking distance

Factors affecting thinking distance

(the driver's reaction time)

- tiredness
- alcohol
- drugs
- distractions, eg using a phone

Typical reaction time: 0.2 s to 0.9 s.

Factors affecting braking distance

- the speed of the vehicle
- poor condition of the brakes
- poor condition of the tyres
- wet or icy road surface
- adverse weather, eg rain or ice

Greater speed → greater stopping distance.

Large decelerations are dangerous

- A greater braking force is needed to stop in a shorter distance, so the deceleration is larger.
- Work done by the friction force between the brakes and the wheel reduces the kinetic energy of the car, so the temperature of the brakes increases. Brakes may overheat and the driver may lose control.

5.6.3.2 Reaction time

- Reaction times vary from person to person; typical values range from 0.2 s to 0.9 s.
- A driver's reaction time is affected by **tiredness, drugs and alcohol**; **distractions** also affect the ability to react.
- **Ruler drop test**: hold a metre rule vertically between a partner's thumb and finger at the zero mark, drop it without warning, and convert the distance fallen into a time. Repeat for a mean, then repeat with a distraction to compare. Computer tests remove some human error.

5.6.3.3 Factors affecting braking distance 1

- Braking distance is affected by **adverse road and weather conditions** — **wet or icy** conditions — and by the **poor condition of the vehicle**, limited to its **brakes or tyres**.

Factors affecting thinking distance	Factors affecting braking distance
Speed of the vehicle	Speed of the vehicle
Tiredness	Wet or icy road conditions
Drugs	Worn or poorly maintained brakes
Alcohol	Worn tyres
Distractions (phone, music)	Mass of the vehicle / load carried

HIGHER TIER

5.6.3.4 Factors affecting braking distance 2

- When a force is applied to the brakes, work done by the friction force between the brakes and the wheel reduces the kinetic energy of the vehicle and the temperature of the brakes increases.
- The greater the speed, the greater the braking force needed to stop in a given distance, and the greater the braking force the greater the deceleration. Large decelerations may lead to brakes overheating and/or loss of control (skidding).
- **HT ONLY** Be able to estimate the forces involved in the deceleration of road vehicles using $F = m a$.

5.7 Momentum HT ONLY

HIGHER TIER

5.7.1 Momentum is a property of moving objects

- **HT ONLY** Momentum is a **vector**: take one direction as positive and the opposite direction as negative.

HIGHER TIER

5.7.2 Conservation of momentum

- **HT ONLY** In a closed system, the total momentum before an event is equal to the total momentum after the event — **conservation of momentum**.
- **HT ONLY** "Event" covers **collisions** and **explosions**: for two trolleys pushed apart by a spring from rest, total momentum before is zero, so their momenta afterwards are equal and opposite.
- **PHYSICS ONLY HT ONLY** Be able to complete **calculations** for an event such as the collision of two objects.

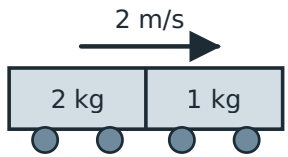
HT ONLY Conservation of momentum in a collision

Higher tier only

Two trolleys collide and stick together

before: 

momentum before = $(2 \text{ kg} \times 3 \text{ m/s}) + (1 \text{ kg} \times 0 \text{ m/s})$
 $= 6 \text{ kg m/s}$

after: 

momentum after = $(2 \text{ kg} + 1 \text{ kg}) \times 2 \text{ m/s} = 6 \text{ kg m/s}$

total momentum before = total momentum after
 momentum is conserved in a closed system
 a closed system: no external forces act on the trolleys

Longer collision time, smaller force

$F = \text{change in momentum} \div \text{time}$
 $F = m \Delta v \div \Delta t$ (equation sheet)

The same change in momentum spread over a longer time gives a smaller force on the people.

Safety features

- crumple zones • air bags
- seat belts • crash mats
- cycle helmets
- cushioned playground surfaces



5.7.3 Changes in momentum **PHYSICS ONLY****HT ONLY**

- **PHYSICS ONLY HT ONLY** When a force acts on an object that is moving, or able to move, a change in momentum occurs. **PHYSICS ONLY HT ONLY** $F = m a$ and $a = (v - u) \div t$ combine to give $F = m \Delta v \div \Delta t$, where $m \Delta v = \text{change in momentum}$ — so force equals the rate of change of momentum. **PHYSICS ONLY HT ONLY** **Safety features increase the time taken for the momentum to change.** For the same change in momentum a longer time means a smaller rate of change of momentum, so a smaller force on the person and less injury: **air bags, seat belts, gymnasium crash mats, cycle helmets, cushioned playground surfaces.**

ANALOGY

Impulse — catching a cricket ball. A fielder pulls their hands back while catching. The change in momentum is fixed, but stretching the catch over a longer time makes the force much smaller, so it stings far less. Rigid hands stop the ball in a tiny time, and the same momentum change then gives a huge force — the principle behind crumple zones, crash mats and air bags.