PCFGSTUDY

AQA GCSE Combined Science: Trilogy — Physics

Topic 22

Forces

Specification 8464 · 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 Displacement

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

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Define Inertia

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

HIGHER TIER

Define Momentum

- mass × velocity. HT ONLY

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 Velocity

- speed in a given direction; a vector.

Define Terminal velocity

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

Define Stopping distance

- thinking distance + braking distance.

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22.1 Forces and their interactions

22.1.1 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

22.1.2 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.

22.1.3 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 ($g \approx 9.8$ N/kg on Earth, ≈ 1.6 N/kg on the Moon) and acts at the **centre of mass**.
- Measured with a **calibrated spring-balance (a newtonmeter)**; weight $\propto$ mass.

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".

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22.1.4 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).

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Free body diagrams

Book on a table

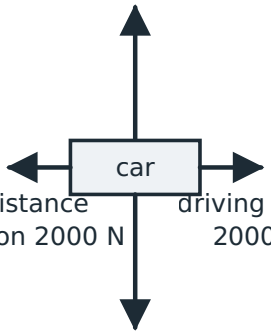
normal contact force from the table 10 N

weight 10 N

Resultant force = 0 N
forces balanced

Car at a steady speed

normal contact force from the road 9000 N



weight 9000 N

Resultant force = 0 N
balanced — constant velocity

Falling skydiver

air resistance 400 N

weight 700 N

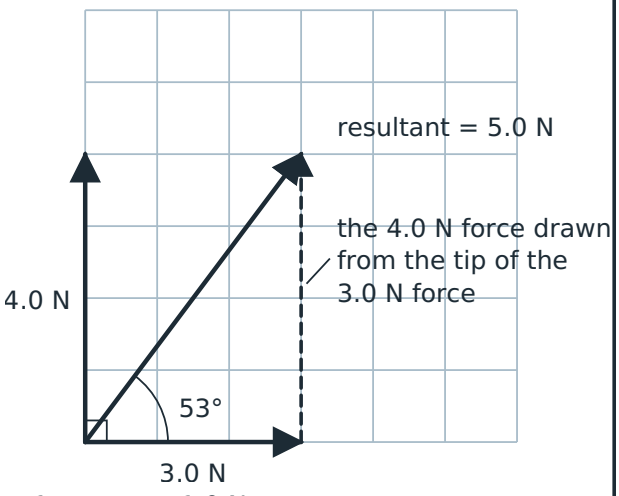
Resultant force = 300 N
downwards — speeds up

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

Adding and resolving forces with a scale diagram

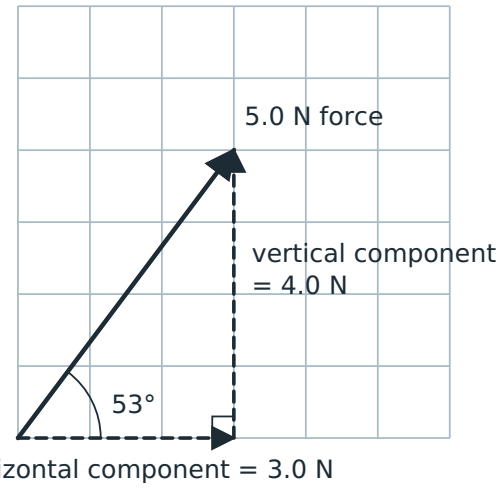
Higher tier only

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



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

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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.

22.2 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.

22.3 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 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.

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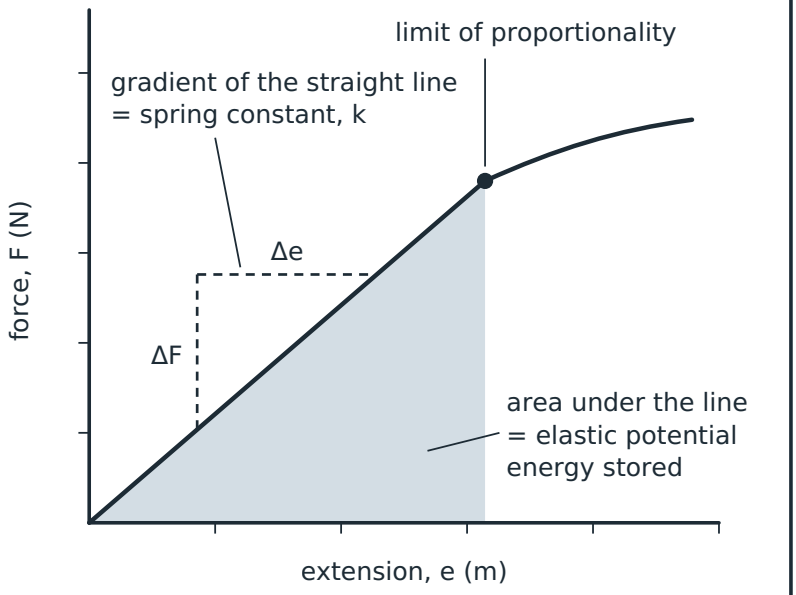
Force–extension graphs for a spring



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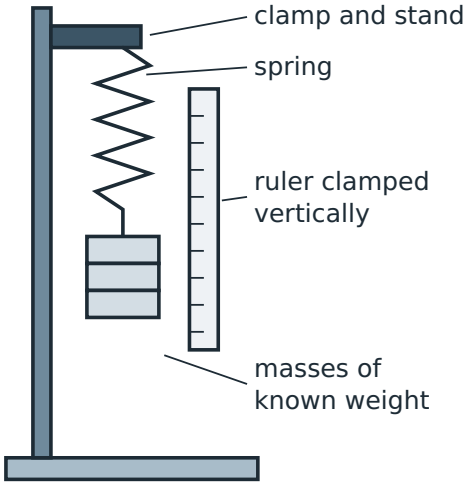

- extension = stretched length − original (unstretched) length
- force is directly proportional to extension up to the limit of proportionality: $F = k\,e$
- gradient of the straight line = spring constant, k (in N/m)
- area under the line = elastic potential energy stored: $E_e = \frac{1}{2} k e^2$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

22.4 Forces and motion

22.4.1 Describing motion along a line

22.4.1.1 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**.

22.4.1.2 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

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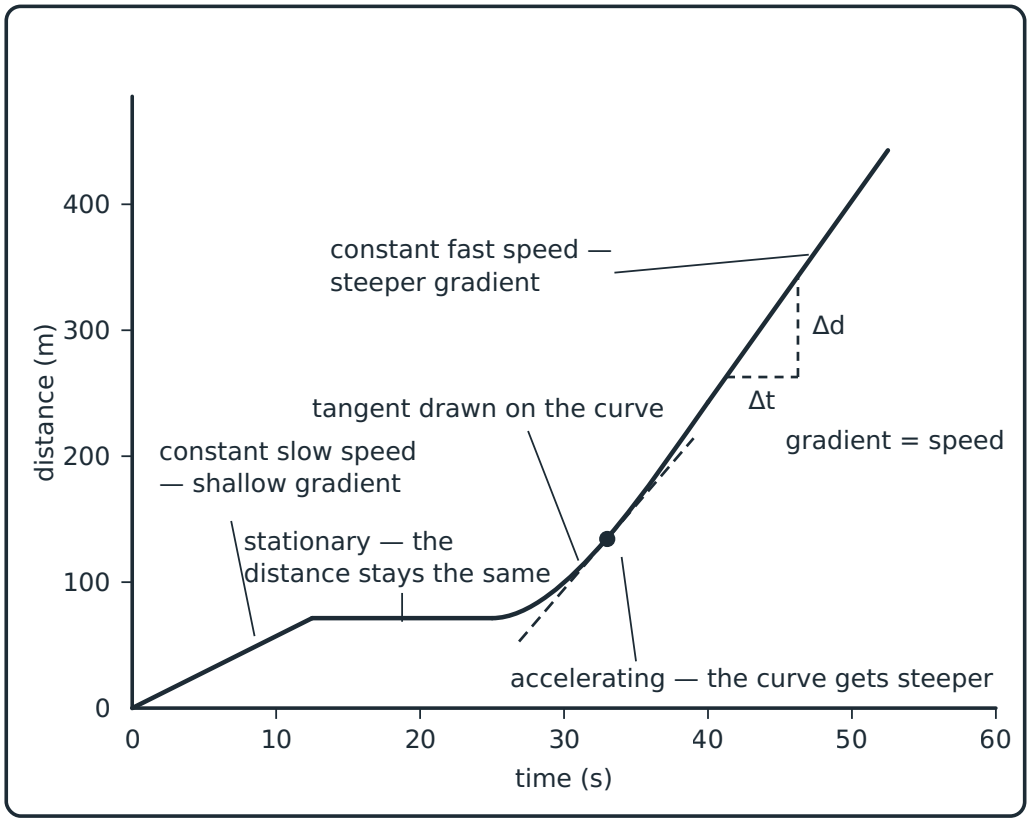
22.4.1.3 Velocity

- 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.

22.4.1.4 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**.

Distance–time graphs



How to read it

- flat line = stationary
- steeper line = faster
- gradient = speed
- speed = distance ÷ 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

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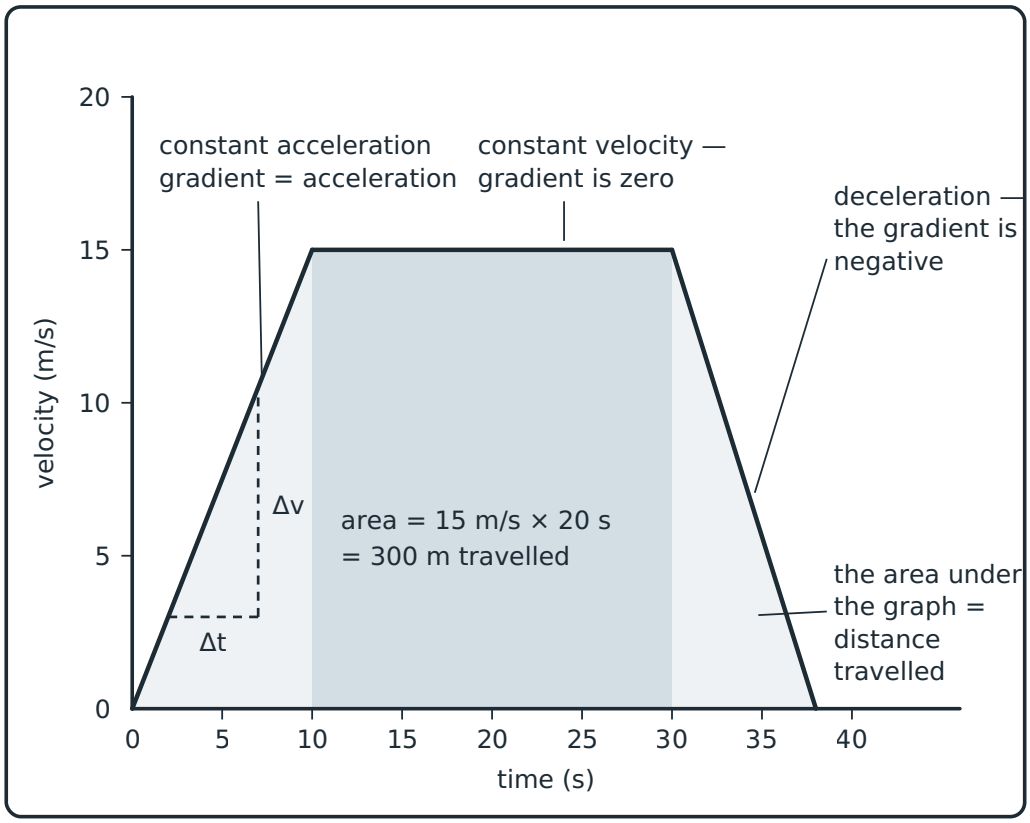
22.4.1.5 Acceleration

- 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/s².
- Estimating everyday accelerations: a car reaching 13 m/s in 6 s gives $a \approx 2$ m/s².

Velocity–time graphs



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**.

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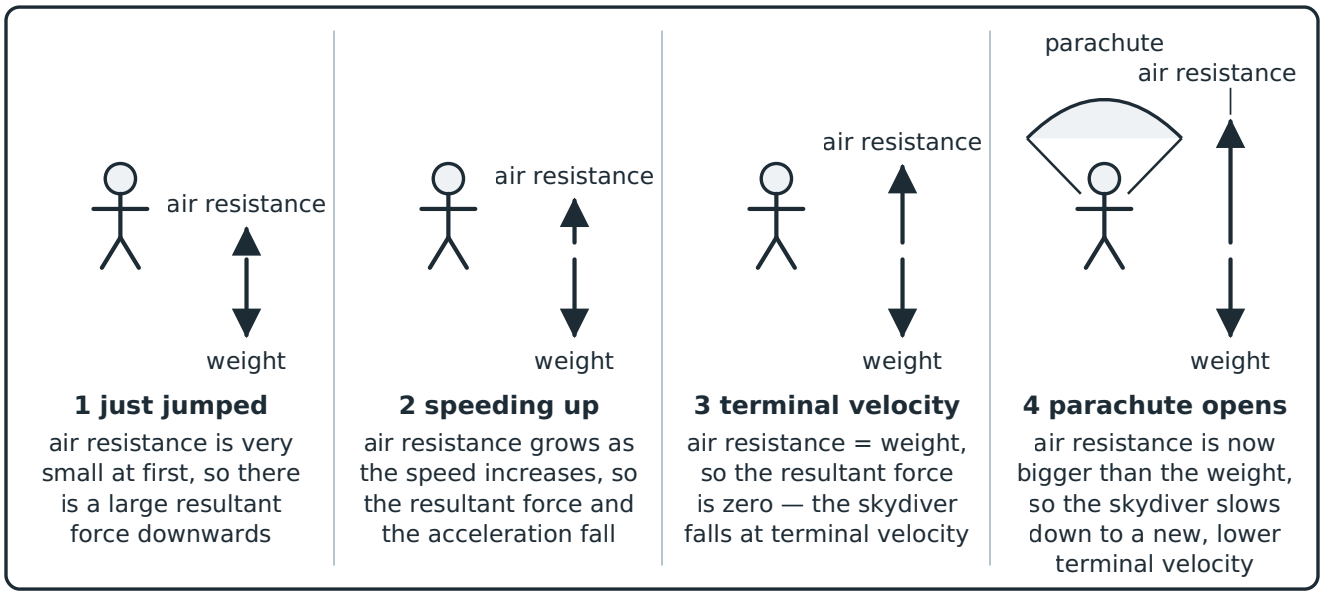
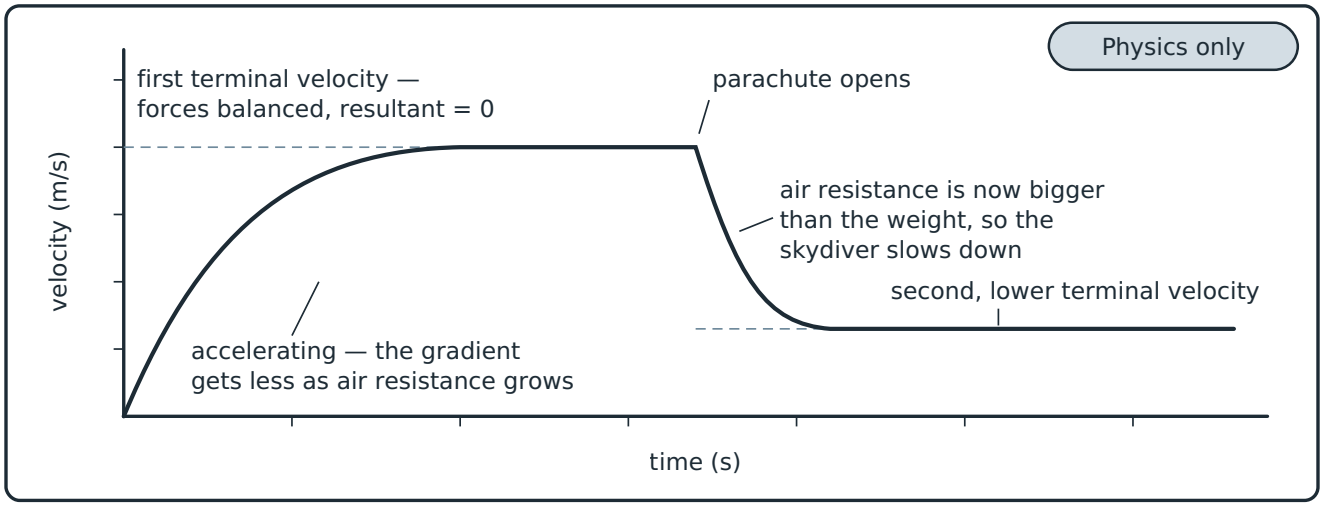
Terminal velocity





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.

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22.4.2 Forces, accelerations and Newton's Laws of motion

22.4.2.1 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**.

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22.4.2.2 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.

22.4.2.3 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.

22.4.3 Forces and braking

22.4.3.1 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 ∝ speed; braking distance grows much faster (roughly with speed squared, since $v^2 - u^2 = 2as$).

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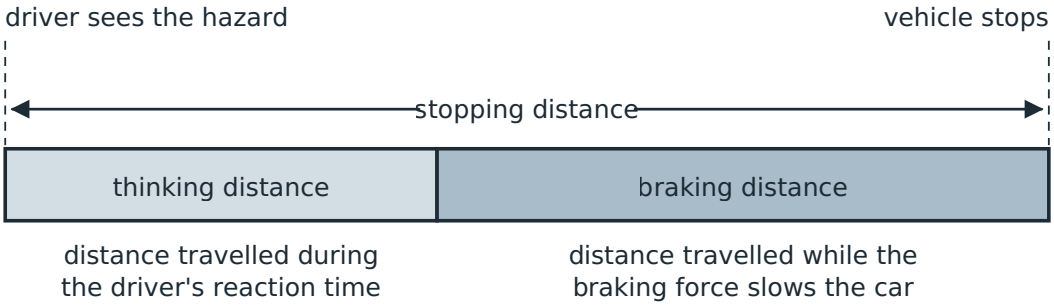
Thinking, braking and stopping distance



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.

22.4.3.2 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.

22.4.3.3 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**.
- Be able to explain the factors which affect the distance required for road transport vehicles to come to rest in emergencies, and the implications for safety, and to estimate how the distance required for road vehicles to stop in an emergency varies over a range of typical speeds.

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

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22.4.3.4 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 $F = m\,a$.

22.5 Momentum HT ONLY

HIGHER TIER

22.5.1 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

22.5.2 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 in size and opposite in direction.
- HT ONLY Use momentum as a model to describe and explain examples of momentum in an event, such as a collision: when a moving trolley collides with a stationary one and they stick together, the moving trolley loses exactly as much momentum as the stationary one gains, so the combined trolleys move off more slowly than the first trolley was travelling.

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Conservation of momentum in a collision

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Two trolleys collide and stick together

momentum before = (2 kg × 3 m/s) + (1 kg × 0 m/s)
= 6 kg m/s

momentum after = (2 kg + 1 kg) × 2 m/s = 6 kg m/s

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total momentum before = total momentum after

momentum is conserved in a closed system

a closed system: no external forces act on the trolleys

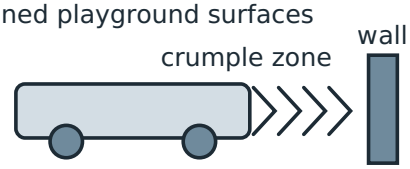
Longer collision time, smaller force

F = change in momentum ÷ time
F = m Δv ÷ Δt (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



ANALOGY

Momentum in a collision is like sharing out money in a sealed room. Nobody can bring cash in or take it out, so however the notes are passed around, the total in the room is the same before and after — momentum simply moves between the objects in a closed system.

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