- Triple Science Content only in purple
- Triple Science and Higher Content Only in blue

GCSE AQA Physics Topic 5

5. Forces

5.1 Forces and their Interactions

5.1.1 Scalar and Vector Quantities

- **Scalar quantities**: Have only magnitude (e.g., mass, speed).
- **Vector quantities**: Have both magnitude and direction (e.g., velocity, force).
- **Representation**: Vectors are represented by arrows; the length indicates magnitude, and the direction of the arrow represents the direction of the vector.

<u>Vector Examples:</u>

Velocity (e.g. 10 m/s north)

Displacement (e.g. 5 m east)

Force (e.g. 50 N upwards)

Acceleration (e.g. 3 m/s² downwards)

Momentum (e.g. 12 kg·m/s forward)

<u>Scalar Examples:</u>

Speed (e.g. 10 m/s)

Distance (e.g. 5 m)

Mass (e.g. 2 kg)

Time (e.g. 20 s)

Temperature (e.g. 25°C)

Energy (e.g. 200 J)

5.1.2 Contact and Non-contact Forces

- **Force**: A push or pull acting on an object due to its interaction with another object (measured in Newtons, N).
- **Contact forces**: Forces where objects physically touch (e.g., friction, air resistance, tension, normal contact force).
- **Non-contact forces**: Forces where objects do not touch (e.g., gravitational force, electrostatic force, magnetic force).

5.1.3 Gravity

- **Weight**: The force acting on an object due to gravity.
  - Weight depends on gravitational field strength (measured in N/kg) and mass.
  - Equation: $W = m \times g$
  - Weight acts towards the centre of the Earth (or other celestial bodies).
- Acceleration in free fall is due to gravity.
- The weight of an object = the objects centre of mass

5.1.4 Resultant Forces

- The **resultant force** is the single force with the same effect as all the combined forces acting on an object.
  - If the resultant force on an object is zero, the object remains stationary or continues at constant speed.
  - If the resultant force is not zero, the object will accelerate in the direction of the resultant force.

Skydiver Example – Resultant Force

When a skydiver jumps out of a plane, several forces act on them. The balance between these forces changes during the fall.

Stage 1 – Just after jumping

- **Forces acting:**
  - **Weight (gravity):** Acts **downwards**, large and constant.
  - **Air resistance (drag):** Acts **upwards**, small at first (since speed is low).
- **Resultant force:**
  - Downwards (because weight > air resistance).
- **Effect:**
  - The skydiver **accelerates downwards**.

Stage 2 – As speed increases

- As the skydiver falls faster:
  - **Air resistance increases** (because drag depends on speed).
  - **Weight stays the same.**
- Eventually, air resistance grows **until it equals the weight**.

Stage 3 – Terminal velocity

- **Weight = Air resistance.**
  Resultant force = 0.
- The skydiver now falls at a **constant speed** — this is called **terminal velocity**.
  - ➜ No acceleration, because forces are balanced.

Stage 4 – Parachute opens

- The parachute suddenly increases **air resistance** (huge surface area).
- **Air resistance > weight**, so the resultant force is **upwards**.
- **Effect:** The skydiver **slows down rapidly** (decelerates).

Stage 5 – New, slower terminal velocity

- As speed decreases, air resistance reduces again.
- Eventually, **air resistance = weight** once more.
- The skydiver falls at a **new, slower terminal velocity**, safe for landing.

Summary Table

Stage	Weight	Air Resistance	Resultant Force	Motion
Just jumped	Large	Small	Downwards	Accelerating
Speed increasing	Constant	Increasing	Decreasing downwards	Accelerating (less)
Terminal velocity	Equal	Equal	0	Constant speed
Parachute opens	Constant	Much larger	Upwards	Decelerating
New terminal velocity	Equal again	Equal again	0	Slower constant speed

5.1.5 Free-body Diagrams and Resolving Forces

- **Free-body diagrams**: Diagrams representing all the forces acting on a single object.
  - Forces are drawn as arrows pointing away from the object.
- **Resolving forces**: A single force can be split into **two components** at right angles to each other (usually horizontal and vertical).

5.1.6 Equilibrium

- An object is in **equilibrium** if the **resultant force** and **resultant moment** on it are zero.
  - **Forces in equilibrium**: All forces acting on the object are balanced, so the object remains at rest or moves at constant velocity.
  - **Moments in equilibrium**: For an object to be in rotational equilibrium, the total clockwise moment must equal the total anticlockwise moment about a pivot.

5.2 Work Done and Energy Transfer

- **Work done** occurs when a force moves an object through a distance.
  - Equation: $W = F \times s$
  - Work done is measured in joules (J), where 1 joule is 1 newton-metre.
  - Work done against friction increases the temperature of the object.

5.3 Forces and Elasticity

- **Hooke's Law**: The extension of an elastic object (e.g., spring) is proportional to the force applied, as long as the limit of proportionality is not exceeded.
  - Equation: $F = k \times e$
- **Elastic and Inelastic Deformation**:
  - **Elastic deformation**: Temporary, where the object returns to its original shape when the force is removed.
  - **Inelastic deformation**: Permanent, where the object does not return to its original shape after the force is removed.
- **Elastic potential energy** is stored when an elastic object is stretched or compressed.
  - Equation: $E_e = \frac{1}{2}ke^2$

5.4 Moments, Levers, and Gears

- **Moment of a force**: The turning effect of a force.
  - Equation: M=F×d
  - **Levers and gears**: Tools that transmit rotational effects of forces, allowing small forces to have large effects.

How moments cause rotation

- If you apply a force at a **distance from the pivot**, it makes the object **rotate**.
- The **larger the force** or **longer the distance**, the **bigger the moment**.
- A force **acting through the pivot** produces **no moment** (since distance = 0).
  ### Example
- A spanner loosening a nut:
  - The nut acts as the **pivot**.
  - The force applied on the handle is at a distance from the pivot.
  - A **longer spanner** increases the **moment**, making it easier to turn the nut.

Direction of moments

Moments can be:

- **Clockwise** (turning in the direction of a clock's hands)
- **Anticlockwise** (turning opposite to clock's hands)

◆ 5. Principle of moments

When an object is **balanced** (not turning):

Total clockwise moment=Total anticlockwise moment

Levers and Gears

Levers

- A **lever** is a rigid bar that pivots around a **fulcrum**.
- Used to **multiply force** and make lifting easier.
- Examples: scissors, crowbar, spanner.
- A **small force** applied at a **large distance** from the pivot can move a **large load** close to the pivot.

Mechanical Advantage:

Mechanical Advantage=Load/Effort

Gears

- **Gears** transfer **rotational effect (moment)** between two shafts.
- **Large gear** and **small gear** turn in **opposite directions**.
- A **large gear** turning a **small gear** increases **speed** but reduces **moment**.
- A **small gear** turning a **large gear** increases **moment** but reduces **speed**.

5.5 Pressure and Pressure Differences in Fluids

5.5.1 Pressure in a Fluid

- **Pressure in fluids** creates a force at right angles to any surface.

Pressure in a Fluid

What is a fluid?

A **fluid** is any substance that can **flow** — this includes **liquids and gases**.
Particles in a fluid move freely, and their **collisions with surfaces** create **pressure**.

Pressure in a fluid (definition)

Pressure is the **force exerted per unit area**.

$$P = F/A$$

Where:

- **P** = pressure (Pascals, **Pa**)
- **F** = force (Newtons, **N**)
- **A** = area (m²)

Pressure at a point in a fluid

In a fluid, pressure acts **in all directions** and **increases with depth**.

$$P = h \times \rho \times g$$

Where:

- **P** = pressure (Pa)
- **h** = height or **depth** of fluid (m)
- **ρ (rho)** = **density** of the fluid (kg/m³)
- **g** = **gravitational field strength** (≈ 9.8 N/kg on Earth)

Explanation

- The deeper you go, the **greater the weight** of fluid above you.
- This **extra weight** causes a **larger pressure** at greater depths.
- Pressure also **depends on the density** — denser fluids exert more pressure.

Example

Question:
Calculate the pressure at a depth of 5 m in water (density = 1000 kg/m³).

P=hρg=5×1000×9.8=49,000 Pa

So pressure = **49 kPa**

How pressure causes upthrust

- In a fluid, **pressure increases with depth**, so the **bottom of an object** experiences a **greater pressure** than the top.

- This difference creates an **upward force** called **upthrust** (or buoyant force).

If upthrust = weight, the object **floats**.
If upthrust < weight, the object **sinks**.

5.5.2 Atmospheric Pressure

- **Atmospheric pressure**: The pressure exerted by the weight of air in the atmosphere.
    - Pressure decreases with altitude as the number of air molecules above a surface decreases.

5.6 Forces and Motion

5.6.1 Describing Motion Along a Line

- **Distance and displacement**: Distance is a scalar quantity (total movement), while displacement is a vector quantity (movement in a specific direction).
- **Speed and velocity**: Speed is scalar, while velocity is vector (speed in a direction).
    - The equation for speed: $v = \frac{s}{t}$
- **Acceleration**: The rate of change of velocity.
    - Equation: $a = \frac{\Delta V}{t}$

Object / Motion	Typical Speed	Notes
Walking	~1.5 m/s	Average adult walking pace
Running	~3 m/s	Moderate jogging speed
Cycling	~6 m/s	Leisurely cycling speed
Car (in town)	~13 m/s	Around 30 mph
Train	~50 m/s	High-speed train (~180 km/h)
Airplane	~250 m/s	Commercial jet (~900 km/h)
Sound in air	~330–340 m/s	Depends on temperature (faster in warmer air)

- If an object was travelling in a circular motion, the object is constantly **changing direction**,
- Therefore the velocity is constantly changing.
- A change in velocity is defined as acceleration so it is accelerating due to the changing direction.

5.6.2 Forces, Accelerations, and Newton's Laws of Motion

- **Newton's First Law**: An object remains at rest or moves at constant speed unless acted upon by a resultant force (inertia).
- **Newton's Second Law**: Acceleration is proportional to the resultant force and inversely proportional to mass.
  - Equation: $F = m \times a$
- **Newton's Third Law**: For every action, there is an equal and opposite reaction.

Stopping distance

The **total stopping distance** of a vehicle is the **sum** of two parts:

Stopping distance=Thinking distance+Braking distance

Thinking distance

- The **distance travelled** by a vehicle **while the driver reacts** (before braking begins).
- Depends on:
    - **Speed** — faster = longer distance before you react.
    - **Reaction time** — affected by:
        - Tiredness
        - Alcohol or drugs
        - Distractions (e.g. phone use)

Equation:

Thinking distance=speed×reaction time

Braking distance

- The **distance travelled after the brakes are applied** until the car stops.
- Depends on:
    - **Speed** (faster = longer braking distance)
    - **Mass** of the vehicle (heavier = longer)
    - **Road surface** (wet/icy = longer)
    - **Tyre condition** (worn tyres = less grip)
    - **Brake condition** (worn brakes = less effective)

Typical relationship:

- **Thinking distance ∝ speed**

- **Braking distance ∝ speed²**

That means doubling your speed **doubles** thinking distance but **quadruples** braking distance.

◆ **2. Momentum**

p=m×v
Where:

- **p** = momentum (kg·m/s)

- **m** = mass (kg)

- **v** = velocity (m/s)

Momentum is a **vector** (has direction).

Conservation of momentum

In a **closed system** (no external forces):

Total momentum before=Total momentum after

Used to calculate velocities after collisions or explosions.

Example:
 If two objects collide and join together:

m1v1+m2v2=(m1+m2)v

Changes in momentum

A **force** is needed to change an object's momentum.

F=ΔpΔt

or

F=m(v−u)t

Where:

- **F** = force (N)

- **Δp** = change in momentum (kg·m/s)

- **Δt** = time taken for change (s)

If the **change in momentum** happens over a **shorter time**, the **force is larger**.

Safety features in vehicles

Safety systems are designed to:

- **Increase the time** over which momentum changes,
- Therefore **reduce the force** on passengers (since F=ΔpΔt)

Seatbelts

- Stretch slightly during a crash.
- Increase the **time taken** for the body to stop.
- Reduce the **force** on the chest.
- Prevent passengers from hitting the dashboard or windscreen.

🚗 Crumple zones

- Areas at the front and rear of a car that **crumple** on impact.
- Increase the **impact time** by deforming gradually.
- Absorb **kinetic energy** and reduce the force on occupants.

🎈 Airbags

- Inflate rapidly in a crash, then deflate slowly.
- Increase the **stopping time** for the head and upper body.
- **Distribute the force** over a larger area (reducing pressure).
- Reduce injuries to the neck and skull.

Summary Table

Concept	Equation / Idea	Purpose / Effect
Thinking distance	speed × reaction time	Depends on driver & speed
Braking distance	increases with speed^2	Depends on road, tyres, brakes
Momentum	p=mv	Quantity of motion
Force–momentum link	F=ΔpΔt	Larger time = smaller force
Seatbelts	Stretch	Increase stopping time
Crumple zones	Deform	Absorb energy, reduce force
Airbags	Inflate	Spread force, slow head down safely

Exam tip:

If a 6-mark question says *"Explain how safety features reduce injury"*, always link your answer like this:

> "They increase the time taken to stop, so the rate of change of momentum decreases.
> Since F=ΔpΔt, this means the force on passengers is smaller."