Statics, Forces, and Moments

Matthew Williams • Physics • May 20, 2026

Statics, Forces, and Moments

Statics deals with objects that are in equilibrium, either at rest or moving at constant velocity. Understanding statics means understanding how forces balance and how they produce turning effects.

Effects of Forces

A force is any push or pull that can change the **motion**, **shape**, or **size** of a body. Specifically, a force acting on a body may produce one or more of the following effects:

- change of position (the body starts or stops moving, or changes direction)
- change of speed (the body speeds up or slows down)
- change of shape (the body is bent, twisted, or deformed)
- change of dimensions (the body is stretched or compressed)

Types of Forces

Forces come from different physical interactions:

Type	Description	Example
Gravitational	Attraction between masses	Weight of an object
Electrostatic	Attraction/repulsion between charges	Force between charged rods
Magnetic	Force on moving charges or magnetic materials	Force between poles
Nuclear	Short-range force holding nucleus together	Proton-proton binding
Normal reaction	Perpendicular contact force from a surface	Floor pushing up on a block
Tension	Force in a stretched string or spring	Weight on a spring

Friction	Resistive force opposing relative motion	Brakes on a wheel
Upthrust	Upward force exerted by a fluid	Buoyancy on a floating boat

Weight and Gravitational Field Strength

Weight is the gravitational force acting on a mass. It acts downward toward the centre of the Earth and is measured in newtons.

$$W = mg$$

where m is mass (kg) and g is gravitational field strength = 10 N kg^{-1} at the Earth's surface (or gravitational acceleration = 10 m s^{-2}).

Mass and weight are not the same. Mass is the amount of matter in an object and does not change with location. Weight depends on the gravitational field strength at that location, an object on the Moon has the same mass but weighs less.

<JustInCase>

Gravitational field strength(g) is defined as the gravitational force per unit mass at a point: $g = W/m$. Its value at the Earth's surface is 10 N kg^{-1}. Note: g is defined as a force per unit mass (N kg^{-1}), not simply as "acceleration due to gravity", though numerically the values are equal.

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Moments (Turning Effects)

A force applied at a distance from a fixed point (pivot) produces a **turning effect**. This is familiar in everyday situations:

- Opening a door: you push near the edge (far from the hinge) because a larger distance from the pivot requires less force to produce the same turning effect.
- A see-saw: the weight of each person turns the beam about the central pivot.
- Using a spanner: a longer handle lets you apply a greater turning effect to tighten or loosen a bolt.

This turning effect of a force is called a **moment** (also called a torque). The moment of a force is defined as the product of the force and the **perpendicular distance** from the pivot to the line of action of the force:

$$T = F \times d$$

where T is the moment in newton-metres (N m), F is the applied force in newtons, and d is the perpendicular distance from the pivot to the line of action of the force.

The perpendicular distance matters. If a force is applied parallel to the moment arm, it produces no turning effect.

Clockwise moments and **anticlockwise moments** are distinguished by direction.

Conditions for Equilibrium

For an object to be in complete equilibrium, two conditions must both be satisfied:

Translational equilibrium: the centre of mass is not accelerating, so there is no net force:

$$\text{sum of upward forces} = \text{sum of downward forces}$$

Rotational equilibrium: the object is not rotating, so there is no net turning effect. This is the **principle of moments**:

$$\text{sum of clockwise moments} = \text{sum of anticlockwise moments}$$

Both conditions must hold simultaneously. A beam can satisfy the force balance yet still rotate if the moments are unequal, and vice versa.

<MomentDiagram />

Principle of moments (2024 Paper 02, Q2)

A uniform metre rule has its centre at the 50 cm mark and is balanced on a fulcrum at the 60 cm mark. A mass of 0.24 kg hangs from the 100 cm end. Find the weight of the metre rule.

The weight of the rule acts at its centre of mass (50 cm mark). The applied mass hangs at 100 cm.

Distances from the fulcrum (at 60 cm):

- 0.24 kg mass: 100 − 60 = 40 cm = 0.40 m (clockwise moment)
- Rule's weight: 60 − 50 = 10 cm = 0.10 m (anticlockwise moment)

Weight of 0.24 kg mass: $W = 0.24 \times 10 = 2.4$ N

Applying principle of moments:

$$2.4 \times 0.40 = W_{\text{rule}} \times 0.10$$

$$0.96 = 0.10\,W_{\text{rule}}$$

$$W_{\text{rule}} = \frac{0.96}{0.10} = 9.6\text{N}$$

Levers and Mechanical Advantage

A **lever** is a rigid bar that can rotate about a fixed pivot (fulcrum). Every lever has three key parts:

- **Fulcrum (F)**: the fixed pivot point
- **Effort (E)**: the force applied to the lever
- **Load (L)**: the force the lever overcomes (the resistance)

Levers are grouped into three classes depending on where the fulcrum sits relative to the effort and load:

Class	Arrangement	Examples
1	Fulcrum between effort and load	See-saw, claw-hammer, scissors, crowbar
2	Load between fulcrum and effort	Wheelbarrow, nut-cracker, can opener
3	Effort between fulcrum and load	Broom, tweezers, tongs, fishing rod

In a **Class 1** lever (e.g. a crowbar), the fulcrum is between the effort and the load. Placing the fulcrum close to the load means a small effort at the long end can lift a heavy load.

In a **Class 2** lever (e.g. a wheelbarrow), the load is between the fulcrum (the wheel) and the effort (your hands). The effort arm is always longer than the load arm, so MA > 1.

In a **Class 3** lever (e.g. tweezers), the effort is between the fulcrum and the load. The effort arm is shorter than the load arm, so MA < 1; the lever trades force for a larger range of motion.

Mechanical advantage (MA) is the ratio of load to effort:

$$\mathrm{MA} = \frac{\mathrm{load}}{\mathrm{effort}}$$

A lever with MA > 1 amplifies force, but the effort moves through a greater distance than the load. Energy is conserved.

Centre of Gravity

The **centre of gravity** of an object is the point through which its total weight appears to act. For a uniform, symmetrical object (cube, sphere, cylinder), the centre of gravity is at the geometric centre.

For an irregular object, the centre of gravity can be found experimentally by suspending it from two or more points in turn and drawing the vertical plumb line through each suspension point. The centre of gravity is where the lines intersect.

Stability

Whether an object topples when tilted depends on the position of its centre of gravity and the width of its base:

Type	Condition	Behaviour when tilted
Stable equilibrium	Centre of gravity is low; base is wide	Returns to original position
Unstable equilibrium	Centre of gravity is high; base is narrow	Topples over
Neutral equilibrium	Centre of gravity at same height throughout	Stays in new position

A tall, narrow object is unstable. A wide, low object is stable. Racing cars are designed with low centres of gravity and wide wheelbases.

Hooke's Law

When a spring (or elastic material) is stretched, the extension is proportional to the applied force, provided the elastic limit is not exceeded. This is **Hooke's Law**:

$$F = ke$$

where F is the applied force (N), k is the spring constant (N m{^{1}), and e is the extension (m).

The **elastic limit** is the maximum force beyond which the spring does not return to its original length when the force is removed. Below the elastic limit, deformation is elastic (reversible). Above it, deformation is plastic (permanent).

On a force-extension graph, the relationship is linear up to the elastic limit. Beyond it, the graph curves and the spring becomes permanently deformed.

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caption="Hooke's Law: extension is proportional to force up to the elastic limit"

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Spring constant (2021 Paper 02, Q1)

A student attaches masses to a spring and records the extension. At a force of 4.2 N, the extension is 18.0 cm.

Step 1: Convert units.

$e = 18.0\text{cm} = 0.180\text{m}\,,\; F = 4.2\text{N}$

Step 2: Apply Hooke's Law.

$$k = \frac{F}{e} = \frac{4.2}{0.180} = 23.3\text{N m}^{-1}$$

Step 3: If the graph is linear and passes through the origin up to this point, the spring obeys Hooke's Law.

The spring constant is 23.3 N m{.

📝 **Exam Tip**

In the Hooke's Law graph question, the gradient of the force-extension graph equals the spring constant

k

. Calculate it using two well-separated points on the straight-line portion only. Do not use points beyond the elastic limit in your gradient calculation.