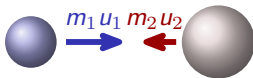


Dynamics

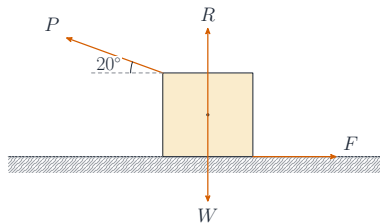
AS Physics ■ Topic 3

A-Level Physics



What we will cover

- 1 Momentum and force
- 2 Newton's three laws
- 3 Weight
- 4 Friction, drag & terminal velocity
- 5 Conservation of momentum
- 6 Recap



1

Momentum and force

Mass and momentum

- **mass** – how hard it is to change motion (a **scalar**, kg)
- **linear momentum** 动量 $p = mv$ – a **vector**, along the velocity

Unit of p : $\text{kg m s}^{-1} = \text{N s}$.



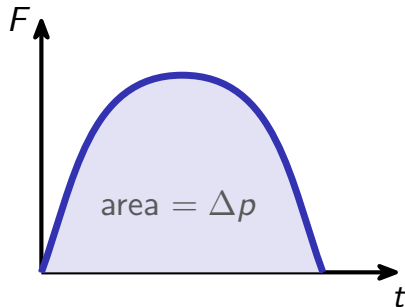
Skydiver terminal

Force is the rate of change of momentum

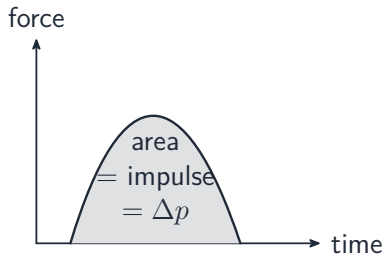
Newton's second law, general form:

$$F = \frac{\Delta p}{\Delta t} \xrightarrow{\text{constant } m} F = ma.$$

Impulse 冲量 $= F\Delta t = \Delta p$ – the **area** under a force–time graph.



Impulse is the area under the force



$F\Delta t = \Delta p$: a small force for a long time changes momentum as much as a large force for a short one – which is what a crumple zone trades.

Impulse = $F\Delta t$ = the **area** under a force–time graph, and it equals the change in momentum. A soft landing spreads the same impulse over a longer time, so the force is smaller.

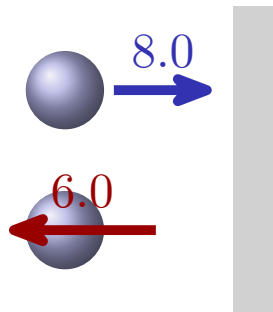
Worked example – ball bouncing off a wall

$m = 0.20 \text{ kg}$: **hits at** 8.0, **rebounds at** 6.0 m s^{-1} , **contact** 0.050 s

Rebound direction +, so $u = -8.0$, $v = +6.0$:

$$\Delta p = m(v - u) = 0.20(6.0 + 8.0) = 2.8 \text{ kg m s}^{-1}$$

$$F = \frac{\Delta p}{\Delta t} = \frac{2.8}{0.050} = 56 \text{ N.}$$



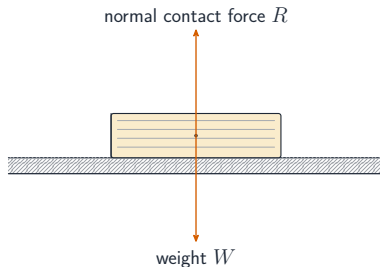
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Newton's laws

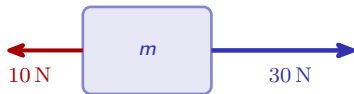
Newton's first law

An object stays at rest, or moves at **constant velocity**, unless a resultant **external force** 外力 acts.

Zero resultant force $\Leftrightarrow$ zero acceleration. This is **inertia**.



Newton's second law



resultant 20 N: 

acceleration a :  same direction

Resultant force = rate of change of momentum:

$$F = \frac{\Delta p}{\Delta t} = ma.$$

Acceleration points the **same way** as the resultant force.

Add forces as **vectors** to get the resultant first.

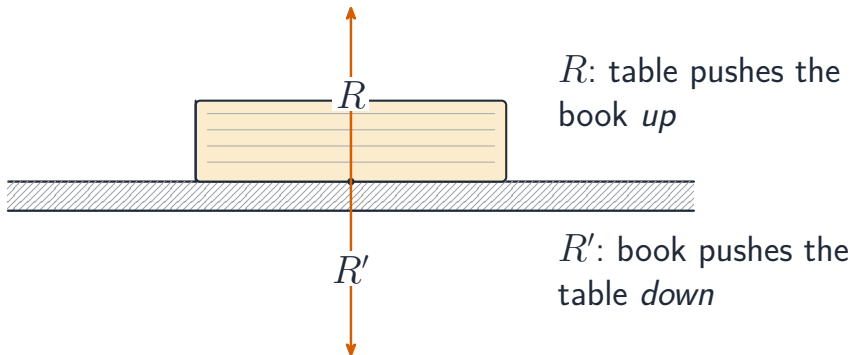
Newton's third law

A on B $\Rightarrow$ B on A: **equal and opposite**. The pair:

- act on **different objects**
- are the **same type** – both gravitational, both contact, both **electrostatic** 静电
- equal size, opposite direction

A book's **weight** 重力 and the table's **normal contact force** 支持力 are **not** a pair – same object, different types. The weight's partner is the pull the book makes on the **Earth**.

Newton's third law, in detail



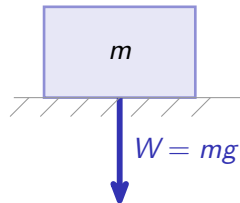
A on B $\Rightarrow$ B on A: **equal and opposite.**

Weight – a gravitational force

Weight 重力 is the pull of a **gravitational field** 重力场:

$$W = mg, \quad g \approx 9.81 \text{ m s}^{-2}.$$

Mass is the **same everywhere**; weight changes with place.



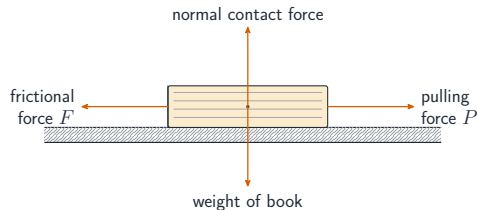
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Friction, drag & terminal velocity

Friction and drag

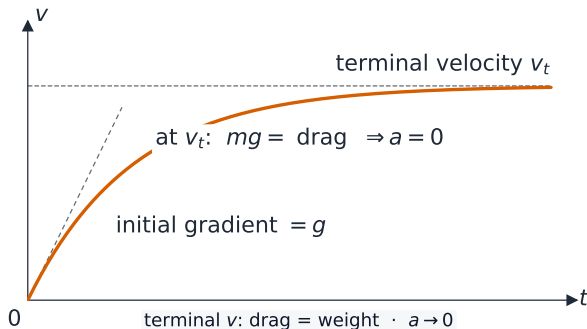
- **friction** 摩擦力 – between solid surfaces, opposes sliding
- **drag** 阻力 (viscous) – from a **fluid** 流体 on a moving object

Drag **grows with speed**; at zero speed the drag is zero. No **coefficient** 系数 of friction or viscosity is needed in this syllabus.



Falling through air – terminal velocity

- 1 only weight $\rightarrow$ speeds up at g
- 2 drag grows $\rightarrow$ acceleration shrinks
- 3 drag = weight $\rightarrow$ **terminal velocity** 收尾速度 (constant)

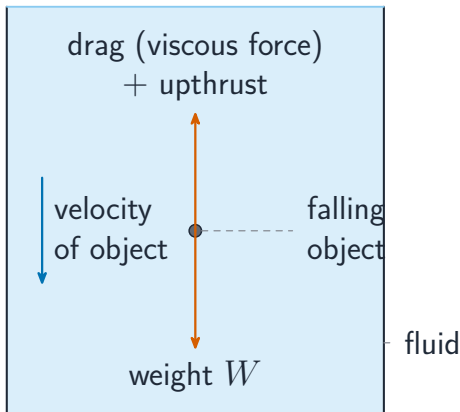


Cyclist or car at constant speed

A vehicle at constant speed on a flat road has zero resultant force.

The forward driving force is equal and opposite to the total resistive force (friction, air resistance, and rolling resistance).

Forces and energy in a fall



At terminal velocity the **parachutist** 跳伞者 has **constant** kinetic energy.

The lost **gravitational potential energy** 重力势能 becomes **thermal energy** of the air – *not* extra kinetic energy.

A car at constant speed: driving force = resistive force; faster $\Rightarrow$ more **power** 功率.

4

Conservation of momentum

Conservation of linear momentum



With **no external resultant force**, total momentum stays constant.

Holds in **collisions**, **explosions** 爆炸 and **recoil** 反冲. In 2-D, it holds along *each* direction.

The principle

For a system with no resultant external force, the total momentum stays constant.

This is **conservation of momentum** 动量守恒.

Worked example – spring release (recoil)

From rest: the 2.0 kg trolley leaves at 6.0 m s^{-1} – how fast is the 3.0 kg?

Total momentum stays **zero**:

$$0 = (2.0)(6.0) + (3.0)(-v)$$

$$v = \frac{12}{3.0} = 4.0 \text{ m s}^{-1} \text{ (opposite way).}$$



equal size, opposite direction
(forces act on different objects)

Newton's third law in an isolated two-particle system: equal and opposite forces

Elastic vs inelastic

Momentum is **always** conserved. Kinetic energy is the difference:

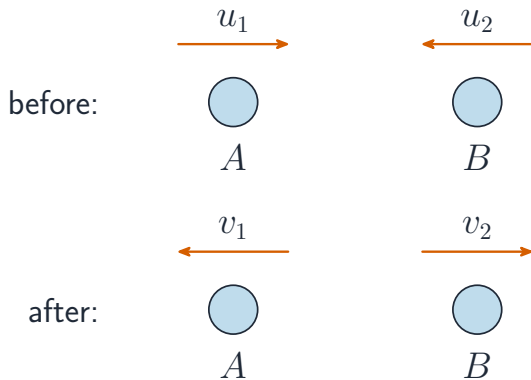
Elastic collision 弹性碰撞

kinetic energy **also** conserved
relative speed of approach =
relative speed of separation

Inelastic collision 非弹性碰撞

kinetic energy **falls** (heat,
sound, **deformation** 形变)
if they stick: perfectly inelastic

Head-on collisions: pick one positive direction



Momentum along that direction is conserved:

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2.$$

Every velocity carries a **sign**: one to the left is **negative**. Choose the direction once and keep it.

An elastic collision gives you a second equation

Momentum alone leaves two unknowns. If the collision is **elastic**, kinetic energy is conserved as well:

$$\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$$

which is quadratic, so use the equivalent form instead:

$$u_1 - u_2 = -(v_1 - v_2)$$

Relative speed 相对速率 of approach = relative speed of separation. Now two linear equations for two unknowns.

Worked example – cars lock together

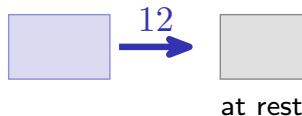
1500 kg at 12 m s^{-1} hits a stationary 1000 kg; they stick

$$1500(12) + 1000(0) = (1500 + 1000) v$$

$$v = \frac{18\,000}{2500} = 7.2 \text{ m s}^{-1}.$$

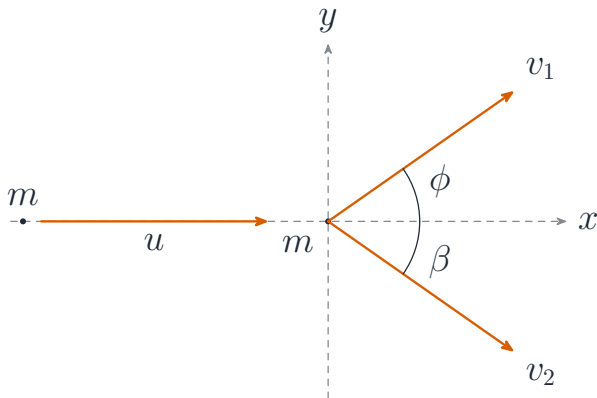
Perfectly inelastic – kinetic energy is lost.

then $v = 7.2$ together



Collisions in two dimensions

Resolve into **perpendicular** 垂直 **components** 分量, then conserve momentum along **each axis**. Choose one axis along the incoming motion, one across it.



Rocket – pushing out mass



Gas leaves at speed u with **mass-flow rate** 质量流率 $\dot{m}$:

$$F = \dot{m} u.$$

From $F = \Delta p / \Delta t$ – the momentum given to the gas each second equals the **thrust** on the rocket (Newton's third law).

Exam tips

- **Newton's second law** is $F = \Delta p / \Delta t$ (rate of change of momentum); $F = ma$ is the special case for constant mass.
- Identify **third-law pairs** correctly: the same type of force, acting on **two different bodies** – not the balanced forces on one body.
- **Momentum is conserved** in every collision; kinetic energy is conserved only in an **elastic** collision.
- For **terminal velocity**, explain that drag rises with speed until drag = weight, so the acceleration becomes zero.

5

Recap

Topic 3 – key takeaways

1

Momentum

$$p = mv; F = \Delta p / \Delta t = ma$$

2

Three laws

inertia; $F = ma$; equal-and-opposite pairs

3

Terminal velocity

drag grows until it balances weight

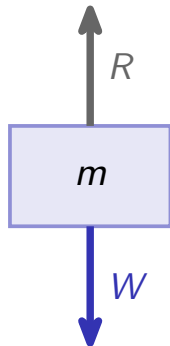
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Conservation

total momentum constant with no external force

Check yourself

- 1 Units of momentum, in terms of N?
- 2 Are a book's weight and the table's push a third-law pair?
- 3 At terminal velocity, what is the resultant force?
- 4 Two trolleys stick on collision – which quantity is conserved?



Answers 1. N s 2. no (same object, different types) 3. zero 4. momentum