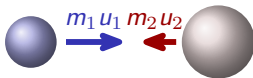


Dynamics

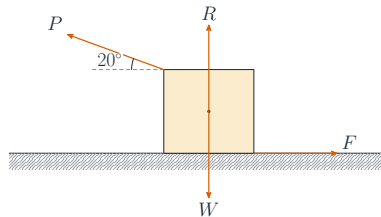
AS Physics ■ Topic 3

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



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



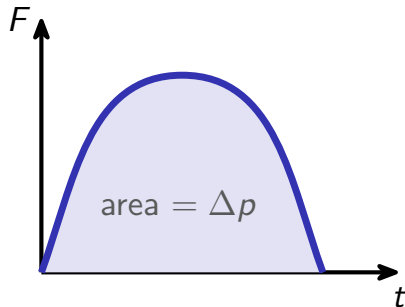
skydiver terminal

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.



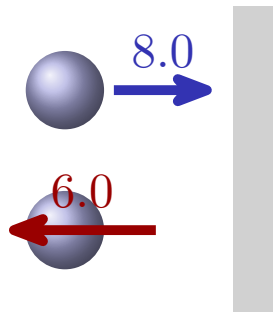
Worked example – ball bouncing off a wall

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

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

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

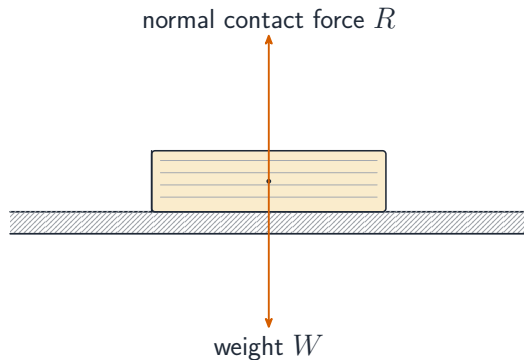
$$F = \frac{\Delta p}{\Delta t} = \frac{2.8}{0.050} = 56 \text{ N.}$$



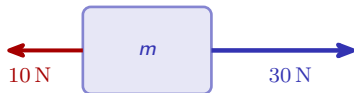
Newton's first law

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.

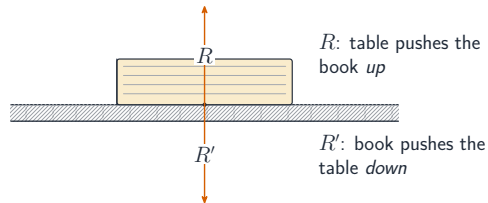
Newton's third law

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

The pair:

- act on **different objects**
- are the **same type** of force
- equal size, opposite direction

A book's weight and the table's push are **not** a pair (same object, different types).

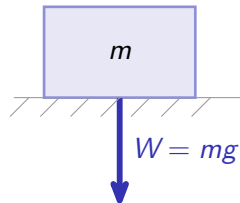


Weight – a gravitational force

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

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

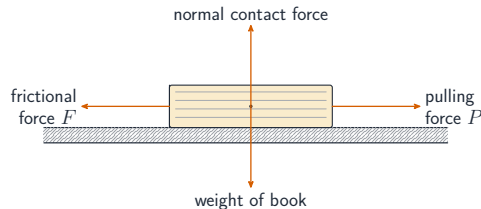
Mass is the **same everywhere**; weight changes with place.



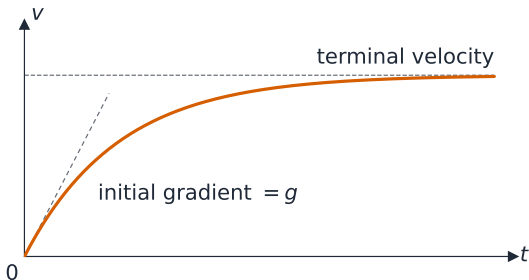
Friction and drag

- **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.

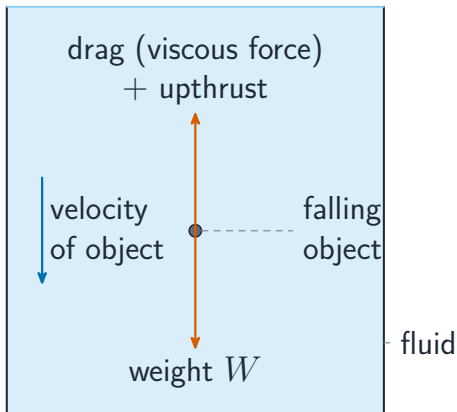


Falling through air – terminal velocity



- 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)

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.

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.

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)

Elastic vs inelastic

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

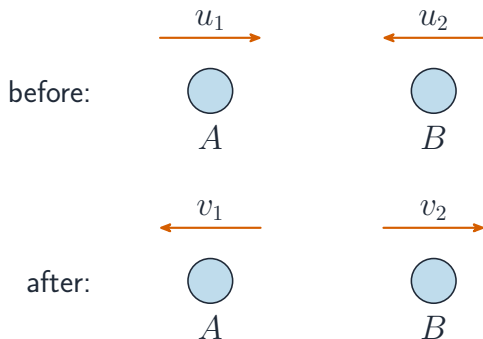
Elastic 弹性

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

Inelastic 非弹性

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

Head-on collisions (one dimension)



Use **signed** velocities along one direction:

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

If elastic, also use

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

Worked example – cars lock together

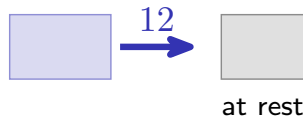
1500 kg at 12 m s^{-1} hits a stationary 1000 kg; they stick

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

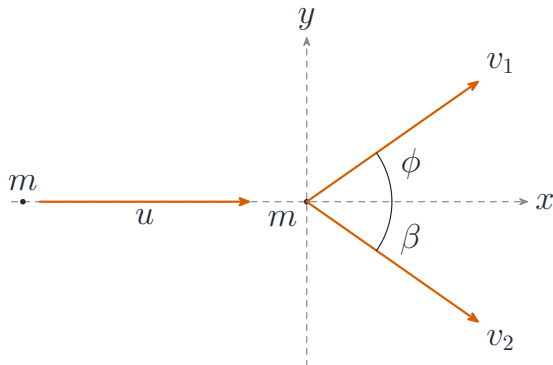
$$v = \frac{18\,000}{2500} = 7.2 \text{ m s}^{-1}.$$

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).

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

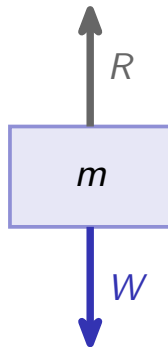
drag grows until it balances weight

4 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