

Dynamics

A-Level Physics 9702 · Topic 3 revision notes · AS

Why motion changes: Newton's laws, momentum and impulse, drag and terminal velocity, and conservation of momentum in collisions.

14 definitions to learn word for word, 10 equations in their own column, 7 diagrams and graphs. Read it, cover it, test yourself.

1. 3.1a Mass, weight and momentum
2. 3.1b Newton's laws of motion
3. 3.2 Non-uniform motion: drag and terminal velocity
4. 3.3 Linear momentum and its conservation

Definitions (mark-scheme wording) Equations Exam traps

3.1a Mass, weight and momentum

Definitions

Mass: the property of an object that resists change in its motion (its inertia).

Weight: the gravitational force acting on an object; $W = mg$.

Linear momentum: the product of mass and velocity.

Newton: the force that gives a mass of 1 kg an acceleration of 1 m s^{-2} .

Impulse: the product of force and the time for which it acts; equal to the change in momentum.

Equations

$$p = mv$$

momentum = mass $\times$ velocity
 kg m s^{-1}

$$W = mg$$

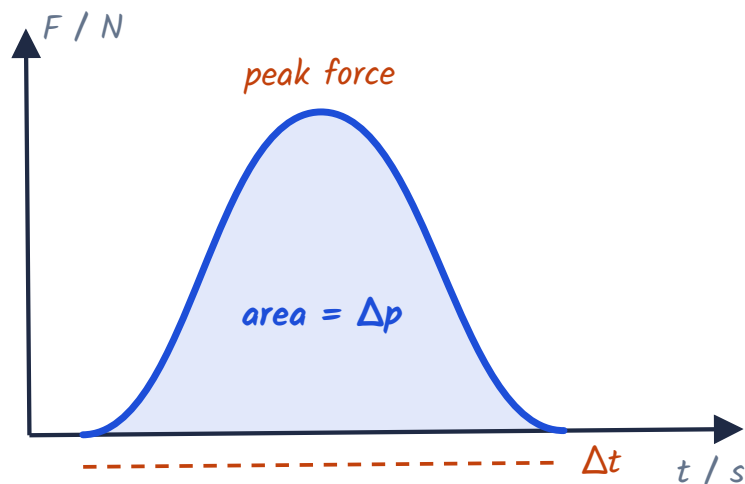
weight = mass $\times$ acceleration of free fall
 N

$$F\Delta t = \Delta p = mv - mu$$

impulse = change in momentum
 N s

Key points

- ✓ Mass is a **scalar** (kg), the same everywhere; weight is a **vector** force (N) that depends on g .
- ✓ Momentum is a **vector** in the direction of the velocity; sign matters when directions reverse.
- ✓ Unit of momentum: $\text{kg m s}^{-1} = \text{N s}$.
- ✓ Force-time graph: **area under the graph = impulse = Δp** .
- ✓ Same Δp over a **longer time** means a smaller force (crumple zones, bending knees, air bags).



Force-time graph for an impact: the shaded area is the impulse, equal to the change in momentum.

Watch out!

- ! Quoting weight in kg. Weight is a force: **newtons**.
- ! A ball bouncing back: $\Delta p = m(v - u)$ with u and v of **opposite sign**, so the magnitudes add.

3.1b Newton's laws of motion

Definitions

Newton's first law: a body remains at rest or continues at constant velocity unless acted on by a resultant force.

Newton's second law: the resultant force on a body is proportional to (equal to) its rate of change of momentum, in the direction of the force.

Newton's third law: if body A exerts a force on body B, then B exerts a force on A that is equal in magnitude, opposite in direction and of the same type.

Equations

$$F = \Delta p / \Delta t$$

resultant force = rate of change of momentum

N

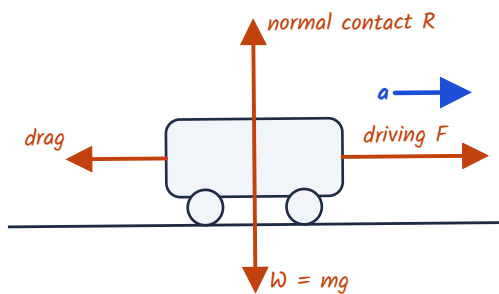
$$F = ma$$

resultant force = mass $\times$ acceleration
(constant mass)

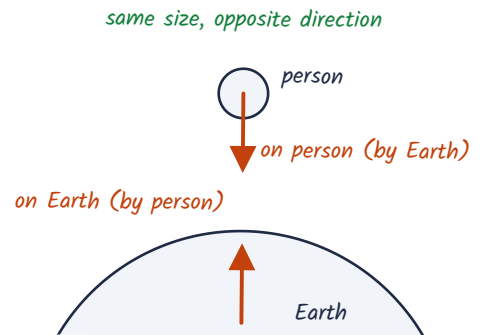
N

Key points

- ✓ Resultant force zero: **no acceleration** (at rest or constant velocity).
- ✓ Resultant force and acceleration are always in the **same direction**.
- ✓ For constant mass the second law gives **$F = ma$** ; use the **resultant** force.
- ✓ Draw a **free-body diagram** for one object before writing $F = ma$.
- ✓ Third-law pairs act on **different bodies**, so they never cancel.
- ✓ Weight of a book and the table push on it are **not** a third-law pair (same body, different types).



Free-body diagram of an accelerating car: only forces **ON** the car; resultant = driving force - drag.



A third-law pair: equal, opposite, same type (gravitational), acting on different bodies.

Watch out!

- ! Using a single force (not the **resultant**) in $F = ma$.
- ! Saying a third-law pair "balances". Balanced forces act on the **same** body; third-law pairs never do.
- ! Constant velocity does not need a forward resultant force: resultant is **zero**.

3.2 Non-uniform motion: drag and terminal velocity

Definitions

Drag: a resistive force on an object moving through a fluid, acting opposite to the velocity.

Terminal velocity: the constant (maximum) velocity reached when the drag force equals the driving force (weight), so the resultant force is zero.

Equations

$$ma = mg - D$$

resultant force on a falling object (down positive)

N

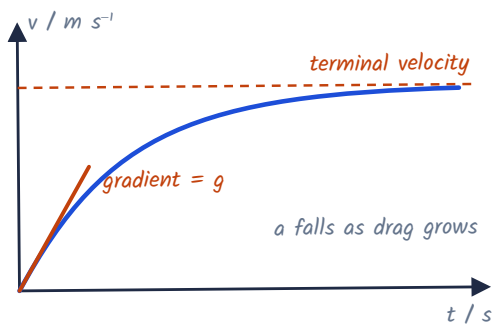
$$D = mg$$

condition for terminal velocity

N

Key points

- ✓ Drag and viscous forces **increase with speed**; they oppose the motion.
- ✓ At release: drag = 0, so $a = g$.
- ✓ As v rises: drag rises, **resultant force falls**, acceleration falls (v - t gradient decreases).
- ✓ Terminal velocity: **drag = weight**, resultant = 0, $a = 0$, v constant.
- ✓ Opening a parachute: drag > weight, so the body **decelerates** to a new, lower terminal velocity.
- ✓ Larger area or less streamlined shape: larger drag, **lower** terminal velocity.



Falling with air resistance: gradient g at release, flattening to the terminal velocity.

$$a = g$$



release



$D < W$



$D = W$

Falling body: at release only W acts; drag grows with speed until $D = W$ (terminal velocity).

Watch out!

- ! At terminal velocity the **acceleration** is zero, not the velocity.
- ! Opening a parachute does not make the diver go up: the velocity stays downward while it **decreases**.

3.3 Linear momentum and its conservation

Definitions

Principle of conservation of momentum: for a system of interacting bodies, the total momentum remains constant provided no resultant external force acts.

Elastic collision: a collision in which total kinetic energy is conserved (as well as momentum).

Inelastic collision: a collision in which total kinetic energy is not conserved (momentum still is).

Perfectly inelastic collision: an inelastic collision in which the bodies stick together and move with a common velocity.

Equations

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

total momentum before = total momentum after

kg m s^{-1}

$$u_1 - u_2 = v_2 - v_1$$

elastic only: approach speed = separation speed

m s^{-1}

$$E_k = p^2 / 2m$$

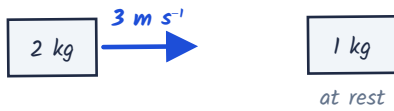
kinetic energy in terms of momentum

J

Key points

- ✓ Momentum is conserved in **all** collisions and explosions (isolated system).
- ✓ Total energy is always conserved; in an inelastic collision KE becomes heat, sound, deformation.
- ✓ Elastic: **relative speed of approach = relative speed of separation**.
- ✓ Explosion from rest: total momentum stays **zero**, so fragments move in opposite directions.
- ✓ Two dimensions: conserve momentum **separately** in two perpendicular directions.
- ✓ Choose a positive direction; velocities the other way are **negative**.

before

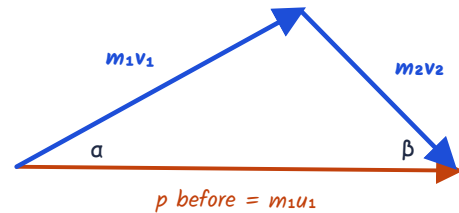


after



Elastic collision check: $p \text{ before} = 6 \text{ kg m s}^{-1}$, $E_k \text{ before} = 9 \text{ J}$,
approach 3 = separation 3 m s^{-1} .

$$\text{along: } m_1 u_1 = m_1 v_1 \cos \alpha + m_2 v_2 \cos \beta$$



$$\text{across: } m_1 v_1 \sin \alpha = m_2 v_2 \sin \beta$$

Oblique collision: the momentum vectors after add tip-to-tail to give the momentum before.

Watch out!

- ! Testing momentum conservation with kinetic energy. KE is conserved **only** in elastic collisions.
- ! Forgetting the minus sign for a body moving in the negative direction after the collision.
- ! Relative speed rule applies to **elastic** collisions only.