17 Rate of Reactions



1 Measuring the Rate

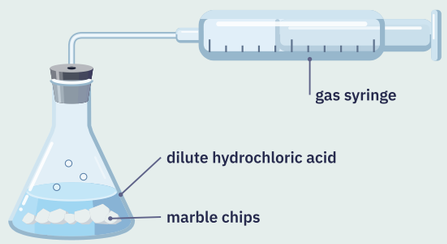
1.1 What the rate is

DEFINITION The **rate of reaction** is how fast a _____ or a _____, measured as the change in amount _____.

- Follow a property that changes as the reaction goes on: the **volume of gas** given off, or the **mass** of the reaction mixture.

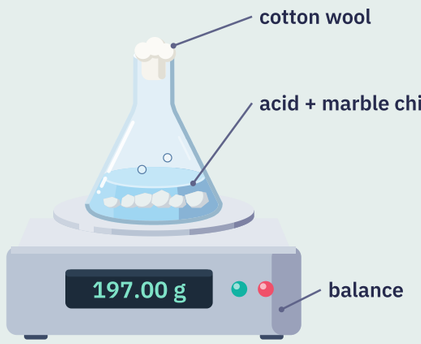
$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

Volume of gas



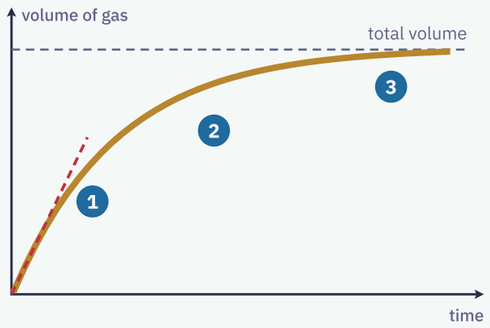
Read the volume in the **gas syringe** at regular time intervals.

Loss in mass



Carbon dioxide escapes, so the mass on the **balance** falls. The cotton wool stops acid spraying out.

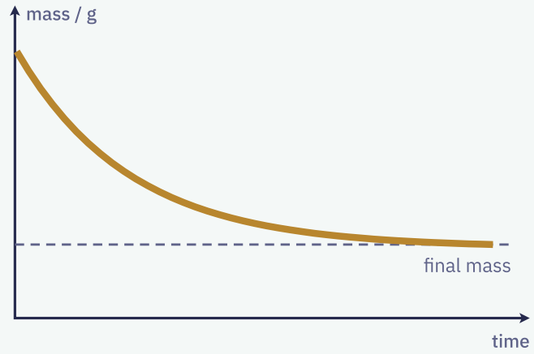
1.2 Reading a rate graph



1. The _____ is the rate. It is steepest at the start, as the reactants are most concentrated.
2. The gradient falls as the reactants are used up, so the reaction _____.
3. The graph _____ when the limiting reactant is used up and the reaction stops.

1 Measuring the Rate (continued)

1.3 Other ways to follow a reaction





- A graph of the **mass of the reaction mixture** against time slopes _____, as the mass of reactants falls. A graph of the mass of a product slopes up.
- When a precipitate forms, time how long it takes for a cross under the flask to **disappear**. A shorter time means a faster rate:

$$\text{rate} ____ \frac{1}{\text{time taken}}$$

$Na_2S_2O_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l) + SO_2(g) + S(s)$

- The yellow precipitate of **sulfur** slowly hides the cross.

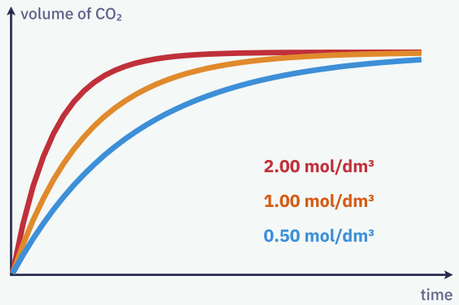
1.4 Planning an investigation

1. Change _____ variable only, e.g. the concentration of the acid.
2. Keep every other variable the _____: the volume of acid, the mass and size of the solid, and the temperature.
3. Measure the volume of gas (or the mass) at _____ with a stopwatch, until it stops changing.
4. Plot the results for each experiment on the **same axes** and compare the initial gradients.

EXAM TIP In a plan, name the apparatus (gas syringe or balance, and stopwatch), say what is kept the same, and say how the result shows the rate: a steeper initial gradient, or a shorter time, means a faster rate.

1 Measuring the Rate (continued)

1.5 Comparing rate graphs



- The curve with the _____ _____ shows the fastest rate.
- The **final volume** depends only on the amount of the _____. Here the marble chips are limiting, so all three end at the same volume.
- Halving the amount of the limiting reactant halves the final volume.

WORKED EXAMPLE The gradient of a mass against time graph is positive when the mass of a product is measured, but negative when the mass of the reaction flask and its contents is measured. Why?

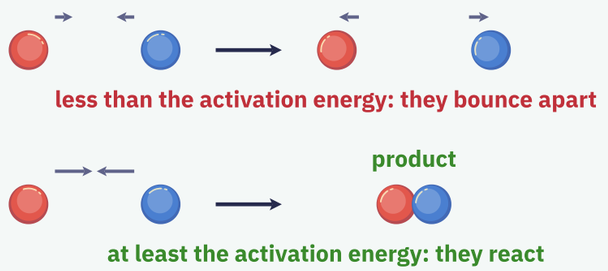
Products form as the reaction goes on, so the mass of a product **increases**: the gradient is positive.

The gas given off escapes from the flask, so the mass of the flask and its contents **decreases**: the gradient is negative.

2 What Affects the Rate

2.1 Effective collisions

Particles react only when they collide with energy _____ the **activation energy**, E_a. Such a collision is an _____.



- The rate increases when the **frequency of effective collisions** increases.

2 What Affects the Rate (continued)

2.2 Concentration and pressure

- A higher **concentration** means more reacting particles _____. They collide more often, so the frequency of effective collisions increases.
- For **gases**, a higher **pressure** pushes the particles closer together, with the same effect. Pressure has almost no effect on solids and liquids.

Concentration (or pressure, for a gas) ↑

1. Number of reacting particles per _____ ↑
2. → frequency of collisions ↑, and hence frequency of _____ ↑ → rate ↑

2.3 Particle size

- Smaller pieces have a larger _____ for the same mass, so more particles are exposed to collide.

Particle size of the solid ↓

1. Larger total _____ of contact
2. → frequency of effective collisions ↑ → rate ↑

WORKED EXAMPLE Explain, in terms of collisions, why powdered marble reacts faster with dilute hydrochloric acid than the same mass of marble lumps.

Powdered marble has a larger **total surface area** of contact with the acid.

This increases the **frequency of effective collisions**, so the rate is faster.

2.4 Temperature

- Particles gain **kinetic energy** and move faster, so they collide _____.
- More particles have energy _____, so a larger fraction of collisions are effective.
- Both increase the frequency of effective collisions, so the rate increases.

Temperature ↑

1. Particles gain kinetic energy and move faster → frequency of collisions ↑
2. → more particles have energy _____, so a larger fraction of collisions are effective
3. → frequency of effective collisions ↑ → rate ↑

EXAM TIP Explain a rate in three links: what changes about the particles, so they collide more frequently (or with more energy), so the **frequency of effective collisions** increases. Say "frequency", not just "more collisions".

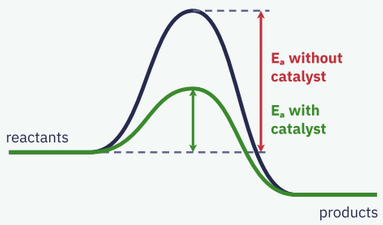
3 Catalysts

3.1 What a catalyst does

DEFINITION A **catalyst** increases the rate of a reaction _____ at the end of the reaction.

- It is not used up, so a small amount works for a long time. Its physical appearance may change.
- It does _____ change the yield of a reaction.
- It is selective: each catalyst speeds up only certain reactions.

3.2 A lower activation energy



- A catalyst provides an _____ with a _____.
- More particles now have energy greater than or equal to the activation energy, so the frequency of effective collisions increases.
- The energies of the reactants and the products are **unchanged**.

Catalyst present

1. Provides an alternative pathway with a lower activation energy
2. → more particles have energy ≥ E_a
3. → frequency of effective collisions ↑ → rate ↑

WORKED EXAMPLE Reaction A has a higher activation energy than reaction B. Under the same conditions, which reaction is faster? Explain your answer.

Reaction **B** is faster.

Its activation energy is lower, so more particles have energy greater than or equal to it.

The **frequency of effective collisions** is higher, so the rate is faster.

3 Catalysts (continued)

3.3 Catalysts in industry and in living things

Catalyst	Used in
_____	the Haber process, to make ammonia
aluminium oxide or silicon dioxide	the cracking of hydrocarbons
_____	making margarine from vegetable oils
platinum, palladium and rhodium	catalytic converters in cars

- Industrial catalysts are usually **transition metals** or their compounds. They let reactions run at lower temperatures and pressures, which saves energy.
- **Enzymes** are _____. They are proteins, and each works best at a particular temperature (often body temperature, 35 to 40 °C) and pH. High temperatures _____ them.