Rates of reaction and equilibrium

Model answers and marking points

GCSE science 6-mark questions

This topic online

1 Limescale is calcium carbonate. It builds up inside kettles in hard-water areas. Descaler is an acid solution that reacts with limescale, giving off bubbles of carbon dioxide.

Ruby notices two things:

- a more concentrated descaler removes the limescale faster
- thin flakes of limescale disappear faster than one thick lump of the same mass

Use collision theory to explain both observations. (6 marks)

Model answer

For the acid to react with the limescale, acid particles must collide with calcium carbonate particles with at least the activation energy. The rate of reaction depends on how often these successful collisions happen.

A more concentrated descaler contains more acid particles in the same volume of solution. This means the acid particles collide with the surface of the limescale more frequently, so there are more successful collisions per second and the limescale is removed faster.

Thin flakes of limescale have a much larger surface area than one thick lump of the same mass, so they have a larger surface area to volume ratio. More of the calcium carbonate particles are exposed to the acid at the same time. This means collisions between acid particles and calcium carbonate particles happen more frequently, so the flakes react faster.

In both cases the particles are not moving any faster and do not have more energy. The rate increases only because collisions happen more often.

Marking points (credit any 6 relevant points, linked in a sensible order)

- Particles must collide with enough energy (the activation energy) to react
- Rate depends on the frequency of successful collisions
- A more concentrated acid has more acid particles in the same volume
- So acid particles collide with the limescale more often, increasing the rate
- Flakes of the same mass have a larger surface area than one lump (larger surface area to volume ratio)
- More calcium carbonate particles are exposed to the acid
- So collisions happen more frequently and the reaction is faster
- Neither change makes particles move faster or gives them more energy
- Both increase the number of collisions per second, not the energy of each collision

How it is marked

- 5-6 marks: explains both observations by more frequent collisions, with the reason for each (more particles per volume, more exposed particles) and links to rate.
- 3-4 marks: explains one observation fully and the other partly, or says 'more collisions' without saying more frequent.
- 1-2 marks: describes the observations or says the particles collide more, with little explanation.

What loses marks

- Saying 'more collisions' instead of more frequent collisions
- Saying higher concentration gives the particles more energy
- Saying the flakes have a smaller surface area because they are smaller pieces

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2 **Higher tier**

Callum reacted zinc granules with excess dilute sulfuric acid and collected the hydrogen in a gas syringe.

Time in s	0	10	20	30	40	50	60
Volume of hydrogen in cm^3	0	24	40	51	57	60	60

Calculate the mean rate of reaction over the first 30 seconds. Explain how Callum could find the rate of reaction at exactly 20 seconds, and explain why the rate changes during the reaction. (6 marks)

Model answer

Mean rate = volume of gas ÷ time = 51 ÷ 30 = 1.7 cm^3/s.

To find the rate at exactly 20 seconds, Callum should plot a graph of volume of hydrogen against time and draw a smooth curve of best fit. He should then draw a tangent to the curve at 20 s, a straight line that just touches the curve at that point. The rate at 20 s is the gradient of the tangent. He can work this out by drawing a large triangle under the tangent and dividing the change in volume by the change in time.

The data show that the rate decreases during the reaction. In the first 10 s, 24 cm^3 of gas is made, then 16 cm^3 in the next 10 s and then 11 cm^3. The curve is steepest at the start. This is because, as the reaction goes on, the zinc is used up, so there are fewer zinc particles for the acid to collide with. Collisions happen less frequently, so the rate falls.

After 50 s the volume stays at 60 cm^3, because all the zinc has reacted and the acid was in excess, so the reaction has stopped.

Marking points (credit any 6 relevant points, linked in a sensible order)

- Mean rate = volume of gas / time taken
- Mean rate over the first 30 s = 51 / 30 = 1.7 cm^3/s
- Plot volume against time and draw a smooth curve of best fit
- Draw a tangent to the curve at 20 s
- Rate at 20 s = gradient of the tangent = change in volume / change in time from a large triangle
- The curve is steepest at the start, so the rate is highest at the start
- As zinc is used up there are fewer zinc particles to react, so collisions become less frequent and the rate decreases
- The volume stops changing at 50 s because the zinc has all reacted (acid in excess)
- Volume gained per 10 s falls from 24 to 16 to 11 cm^3, showing the slowing rate

How it is marked

- 5-6 marks: correct mean rate with units, a clear tangent method for the rate at 20 s, and an explanation of the falling rate using decreasing reactant and collision frequency, with the end point identified.
- 3-4 marks: correct mean rate and either the tangent method or the explanation of the changing rate.
- 1-2 marks: a calculation with an error or missing units, or a statement that the reaction slows down.

What loses marks

- Leaving out the units cm^3/s
- Calculating the mean rate at 20 s (40 / 20) and calling it the rate at 20 s
- Saying the reaction stops because the acid runs out when the acid was in excess

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3 Flour is made of tiny particles and can burn in air. A sack of flour is hard to set alight. However, if a cloud of fine flour dust in a mill meets a spark, it can cause a violent explosion.

Suggest why a dust cloud of flour reacts so much faster than flour in a sack. Suggest two ways the mill could reduce the risk of an explosion, and explain each one. (6 marks)

Model answer

When flour burns, it reacts with oxygen in the air. In a sack, the flour is packed tightly, so only the flour at the outside surface is in contact with oxygen. This is why it burns slowly and is hard to set alight.

In a dust cloud, the tiny flour particles are spread out with air all around each one. This means the flour has a much larger surface area exposed to oxygen. Collisions between flour and oxygen particles happen far more frequently, so the reaction is very fast. The spark provides the activation energy to start the reaction. Combustion is exothermic, so the energy released heats the neighbouring particles so that they react too, and the reaction spreads through the cloud almost instantly. Heat and hot gases are produced so rapidly that they cause an explosion.

One way to reduce the risk is to use ventilation and extraction fans and clean regularly, so dust does not build up in the air and there is less flour exposed to oxygen. Another way is to prevent sparks and flames, for example by using sealed electrical equipment and banning smoking, so nothing can supply the activation energy.

Marking points (credit any 6 relevant points, linked in a sensible order)

- Burning flour is a reaction between flour and oxygen in the air (combustion)
- In a dust cloud the tiny particles are spread out with air all around them
- So the flour has a much larger surface area exposed to oxygen than flour packed in a sack
- More frequent collisions between flour and oxygen particles, so the rate is much higher
- In a sack only the outside surface can meet oxygen, so it burns slowly
- The spark provides the activation energy to start the reaction
- Combustion is exothermic: energy released heats nearby particles so the reaction spreads very quickly
- Gases and heat produced very rapidly cause the explosion
- Reduce risk: extract or remove dust with ventilation and cleaning, so there is less exposed flour
- Reduce risk: prevent sparks and flames (sealed electrics, no smoking) so activation energy is not supplied

How it is marked

- 5-6 marks: explains the speed of the dust cloud reaction using surface area and collision frequency, mentions the spark as activation energy, and gives two sensible safety measures each linked to the chemistry.
- 3-4 marks: links fine dust to a larger surface area and a faster reaction, with one explained safety measure or two unexplained ones.
- 1-2 marks: says dust burns faster or gives a safety measure with no explanation.

What loses marks

- Saying the dust has more energy or is more reactive than flour in a sack
- Saying smaller particles have a smaller surface area
- Giving safety measures without explaining how they reduce the risk

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4 **Higher tier**

A factory makes a gas Z from gases X and Y in a reversible reaction:

$X(g) + 2Y(g) \rightleftharpoons Z(g)$ The forward reaction is exothermic.

Temperature in °C	Yield of Z at 50 atm in %	Yield of Z at 150 atm in %	Time to reach equilibrium at 150 atm
200	62	81	9 hours
300	38	60	40 minutes
400	18	35	5 minutes

Use the data and your knowledge of equilibrium to evaluate which conditions the factory should use.

(6 marks)

Model answer

In a closed system this reaction reaches a dynamic equilibrium, where the forward and reverse reactions happen at the same rate. If the conditions change, the position of equilibrium shifts to counteract the change.

The forward reaction is exothermic, so lowering the temperature shifts the equilibrium to the right, making more Z. The data agree: at 150 atm the yield is 81% at 200 °C but only 35% at 400 °C. However, at a low temperature the reaction is very slow, taking 9 hours to reach equilibrium, so the factory would produce very little Z per day.

There are 3 molecules of gas on the left and only 1 on the right. Increasing the pressure shifts the equilibrium towards the side with fewer gas molecules, so the yield increases. The data show the yield is higher at 150 atm at every temperature. However, high pressure needs a lot of energy and strong, expensive equipment, and it is more dangerous.

A catalyst would help the reaction reach equilibrium faster without changing the yield, and unreacted X and Y can be recycled.

Overall, I think 300 °C and 150 atm is the best compromise, because it gives a reasonable 60% yield in only 40 minutes.

Marking points (credit any 6 relevant points, linked in a sensible order)

- In a closed system the reaction reaches dynamic equilibrium: forward and reverse rates are equal
- If conditions change, the position of equilibrium shifts to counteract the change
- Forward reaction is exothermic, so lowering the temperature shifts equilibrium to the right, increasing yield (data: 200 °C gives highest yield)
- Low temperature makes the reaction very slow: 9 hours to reach equilibrium
- Left side has 3 molecules of gas, right side has 1
- Increasing pressure shifts equilibrium to the side with fewer gas molecules, so yield increases (data: 150 atm higher at every temperature)
- High pressure is expensive (energy, strong equipment) and more dangerous
- A catalyst would speed up reaching equilibrium without changing the yield
- Unreacted X and Y can be recycled
- Conclusion: compromise such as 300 °C and 150 atm: reasonable yield (60%) reached quickly (40 minutes)

How it is marked

- 5-6 marks: explains the effects of both temperature and pressure on yield using equilibrium shifts and the data, weighs yield against rate and cost, and gives a justified compromise.
- 3-4 marks: explains the effect of one condition on yield using equilibrium and uses data, with some idea of a compromise.
- 1-2 marks: chooses the conditions with the highest yield, or quotes data, with little explanation.

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What loses marks

- Choosing 200 °C because it has the highest yield without considering rate
- Saying a catalyst increases the yield
- Saying higher temperature always increases yield because it increases rate

5 A chemical company wants to speed up a slow reaction. Engineer Nadia suggests heating the reactants to a higher temperature. Engineer Sanjay suggests adding a catalyst instead.

Compare how the two methods increase the rate of reaction, and compare their advantages and disadvantages for the company.

(6 marks)

Model answer

Both methods increase the rate of the reaction, but they work in different ways.

When the temperature is increased, the particles move faster, so they collide more frequently. Also, more of the particles have energy equal to or greater than the activation energy, so a greater proportion of the collisions are successful. Both effects increase the rate.

A catalyst does not make the particles move faster. Instead, it provides a different pathway for the reaction with a lower activation energy. This means more of the collisions that happen have enough energy to react, so the rate increases.

A catalyst is not used up in the reaction, so only a small amount is needed and it can be used again and again. Heating, on the other hand, needs a continuous supply of energy, which costs money and may come from burning fossil fuels. However, catalysts can be expensive to buy and each catalyst only works for particular reactions, so the company would need to find one that suits this reaction. Neither method changes the amount of product that can be made from the reactants.

Overall, a catalyst is usually the cheaper long-term choice if a suitable one exists.

Marking points (credit any 6 relevant points, linked in a sensible order)

- Both methods increase the rate of reaction
- Higher temperature: particles move faster, so they collide more frequently
- Higher temperature: more particles have energy equal to or greater than the activation energy, so a greater proportion of collisions are successful
- Catalyst: provides a different reaction pathway with a lower activation energy
- Catalyst: more collisions are successful even though the particles do not move faster
- A catalyst is not used up, so it can be reused and only a small amount is needed
- Heating needs a continuous supply of energy, which costs money and may come from burning fossil fuels
- Catalysts can be expensive to buy and each one only works for particular reactions
- Neither method changes the amount of product made from the same amount of reactants
- Conclusion: a catalyst is usually cheaper in the long run if a suitable one exists, because it is reused and avoids continuous heating costs

How it is marked

- 5-6 marks: compares how each method works in terms of collisions and activation energy, point by point, and compares at least two practical advantages or disadvantages.
- 3-4 marks: explains one method well in terms of particles and the other partly, with at least one practical comparison.
- 1-2 marks: states that both speed up the reaction or gives one simple difference.

What loses marks

- Saying a catalyst gives particles more energy or makes them move faster
- Saying higher temperature lowers the activation energy
- Describing each method separately with no comparison

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