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ANSWER BOOK

The Maxwell–Boltzmann distribution, temperature and catalysts

Kinetics · Unit C05

AQA 3.1.5.2, 3.1.5.3, 3.1.5.5 · OCR A 3.2.2

15 questions · 51 marks

NAVY EDITION

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SECTION A · Short, 1 to 2 marks

A1 MBD-Q2

B1 the most probable energy is the energy at the peak of the curve. **B1** the mean energy lies to the right of the peak, at a higher energy than the most probable energy. [2]

A2 MBD-Q9

B1 chlorine atoms are a homogeneous catalyst, because they are in the gas phase with the ozone. **B1** nickel is a heterogeneous catalyst, because it is a solid and the reactants are a gas and a liquid. [2]

SECTION B · Standard, 3 to 5 marks

B1 MBD-Q10

B1 axes labelled number of molecules, vertical, and energy, horizontal; ignore units. **B1** the curve starts at the origin, rises to a single peak and falls in a long tail to the right. **B1** the tail approaches the energy axis but does not touch or cross it; a tail that meets the axis loses this mark. **B1** the most probable energy is marked at the peak and the mean energy to the right of the peak. **B1** Ea is marked well to the right of the peak, with the area under the curve beyond it shaded. [5]

B2 MBD-Q19

B1 axes labelled enthalpy and progress of reaction, with the product level below the reactant level. **B1** two humps between the same reactant and product levels, the catalysed one lower. **B1** the activation energy of each route drawn from the reactant level to the top of its own peak. **B1** a single ΔH arrow from the reactants to the products, the same for both routes. **B1** the catalyst lowers the activation energy of the forward and reverse reactions equally, so the position of equilibrium is unchanged and is only reached sooner. [5]

B3 MBD-Q14

B1 raising the temperature changes the distribution: the peak moves right and lower, with the same area. **B1** a catalyst leaves the distribution unchanged and moves the activation energy to a lower value. **B1** in both cases more molecules have energy at least equal to the activation energy that applies, so more collisions are successful per unit time and the rate rises. **B1** raising the temperature also makes collisions slightly more frequent, whereas a catalyst does not change the collision frequency. [4]

B4 MBD-Q3

B1 it starts at the origin because no molecules have zero energy. **B1** it never meets the axis because there is no maximum energy: a very small number of molecules have very high energies. **B1** the total area under the curve is the total number of molecules in the sample. [3]

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B5 MBD-Q5

B1 at the higher temperature more molecules have energy at least equal to the activation energy. **B1** so a greater proportion of collisions are successful, and there are more successful collisions per unit time. **B1** molecules also move faster and collide slightly more often, but this is the smaller effect. [3]

B6 MBD-Q6

B1 the activation energy lies far out in the tail of the distribution, where few molecules have that much energy. **B1** a small rise in temperature spreads the curve to the right, and the number of molecules with at least Ea rises by a large proportion, nearly doubling. **B1** the collision frequency rises by only a few per cent, so almost all of the increase in rate comes from the larger number of molecules with at least Ea. [3]

B7 MBD-Q7

B1 a catalyst provides an alternative reaction route with a lower activation energy. **B1** the distribution is unchanged, but the area beyond the lower Ea is larger, so more molecules have energy at least equal to the activation energy. **B1** a greater proportion of collisions are successful, so there are more successful collisions per unit time. [3]

B8 MBD-Q12

B1 the catalyst and the exhaust gases are cold when the engine starts. **B1** even on the catalysed route few molecules have energy at least equal to the lowered activation energy at that low temperature. **B1** so few collisions on the catalyst surface succeed and the rate of conversion is low until the hot exhaust has warmed the converter. [3]

B9 MBD-Q13

B1 a large Ea lies far out in the tail of the distribution, where the number of molecules falls steeply with energy. **B1** stretching the curve to the right by warming multiplies the small area beyond a large Ea by a large factor. **B1** a small Ea lies nearer the peak, where a large share of the molecules already exceeds it, so the same warming changes that area by a smaller proportion. [3]

B10 MBD-Q15

B1 the statement is wrong: a catalyst does not change the energies of the molecules, so the Maxwell–Boltzmann distribution is unchanged. **B1** a catalyst provides an alternative route with a lower activation energy. **B1** more molecules already have enough energy for the lower barrier, so the statement is right that more molecules react but wrong about why. [3]

B11 MBD-Q20

B1 every atom of the reactants ends up in the one product, so the atom economy is 100%. **B1** there are no by-products to separate or dispose of, so less waste and less energy is spent on separation. **B1** the catalyst gives a lower activation energy route, so a useful rate is reached at a moderate temperature with less fuel burnt. [3]

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B12 MBD-Q21 [3]

B1 doubling the concentration doubles the number of collisions in a given time, so at most it doubles the rate; the fraction of collisions that succeed is unchanged. **B1** raising the temperature shifts the Maxwell–Boltzmann distribution towards higher energies, and only the tail of the curve lies beyond a large Ea, so the fraction of molecules with energy at least Ea can rise by far more than a factor of two. **B1** collisions also become a little more frequent at the higher temperature, but for a large Ea the rate more than doubles: for Ea = 100 kJ mol^{-1}, 298 → 308 K multiplies it by about 3.7; accept a numerical estimate.

SECTION C · Long, 6 marks or more

C1 MBD-Q17 [6]

Indicative content

B1 a catalyst provides a route with a lower activation energy, so a useful rate is reached at a lower temperature. **B1** less fuel is burnt to heat the plant, which lowers the energy cost and the carbon dioxide released. **B1** the reaction is exothermic, so a lower temperature gives a higher equilibrium yield, while a catalyst does not change the position of equilibrium. **B1** the catalyst is not used up, and as a solid it stays in the reactor and does not need separating from the products. **B1** against that, the catalyst costs money and must be replaced, and impurities in the feed can poison its surface. **B1** on balance a catalyst is preferred where the saving in energy and the gain in yield outweigh its cost, as in the Haber process, where iron gives a useful rate at about 450 °C.

Levels

Level 3 (5–6 marks) the advantages of the catalyst over a higher temperature are all explained, the lower activation energy, the saving in fuel and carbon dioxide, and the higher equilibrium yield of the exothermic reaction, together with its ease of separation and the disadvantages of cost and poisoning, ending with a justified conclusion.

Level 2 (3–4 marks) the lower activation energy and the energy saving are explained and one drawback is given; the higher equilibrium yield for an exothermic reaction, or the conclusion, is not there.

Level 1 (1–2 marks) the catalyst is said to lower the activation energy or save energy, often with the claim that it also shifts the equilibrium to the right.

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