

2.4.3 Collision evidence, tangents and industrial data

Name: _____ Class: _____ Date: _____

Total: 25 marks

KEY WORDS activation energy

Objective

Distinguish collision frequency from the energy distribution, construct a tangent and justify industrial conditions from data. All questions, data and marking guidance are original.

1 Key knowledge and worked examples

Increasing concentration or gas pressure at fixed temperature increases collision frequency; it does not automatically increase the fraction of particles above the activation energy. Heating changes the distribution: the same population has a lower peak at higher energy and a greater high-energy fraction. A catalyst at fixed temperature leaves that distribution unchanged but lowers the threshold for a different pathway.

■ Worked comparison

In a stated simple model, successful-collision rate is proportional to collision frequency multiplied by the fraction of sufficiently energetic collisions. If frequency becomes 1.20 times larger and that fraction rises from 0.020 to 0.050, the predicted rate factor is $1.20 \times (0.050/0.020) = 3.00$. Do not infer an exact factor from temperature alone without a model or measurements.

To find instantaneous rate, draw a straight tangent that matches the curve locally. Choose two widely separated points on that tangent and calculate $\Delta\text{volume}/\Delta\text{time}$. The tangent may cross the curve elsewhere; nearby curve points do not define the required gradient.

An industrial choice must meet the stated yield and rate requirements. Greater equilibrium yield alone may come with an impractically slow rate. A catalyst changes how quickly equilibrium is approached, not the equilibrium yield at a fixed temperature.

2 Practice

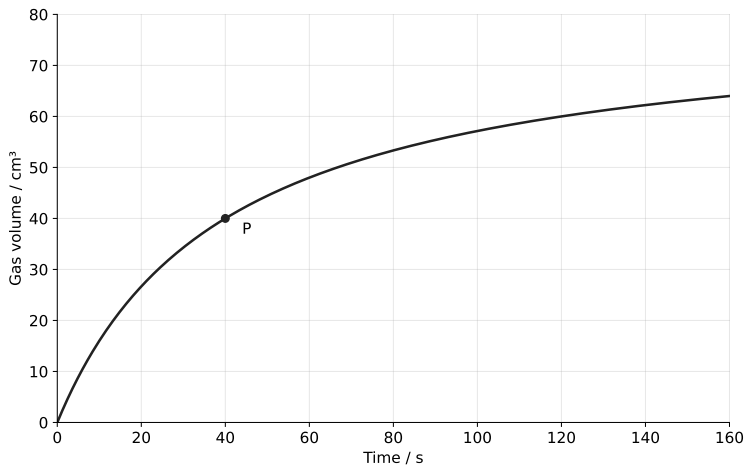
2.1 Two hydrogen-peroxide solutions have different concentrations but the same temperature and volume. Equal amounts of the same catalyst are used. Explain the faster initial reaction in the more concentrated solution, and assess the claim that its molecules must have a larger mean kinetic energy. [3]

2.2 A reacting gas mixture is compressed at constant temperature, with composition initially unchanged. Explain the immediate effect on collision frequency and the fraction of molecules above the same activation energy. Do not assume that doubling pressure necessarily doubles reaction rate. [3]

2.3 A simple collision model predicts rate proportional to collision frequency times the fraction of sufficiently energetic collisions. On heating, collision frequency becomes 1.08 times its previous value and the energetic fraction changes from 0.030 to 0.060. Calculate the predicted rate factor and identify which change contributes more. [3]

3 Exam-style questions

3.1 Draw a tangent to the gas-volume curve at P, then calculate instantaneous rate there. Show a large gradient triangle and its coordinates. Explain why joining the origin to P gives a different rate. [4]



3.2 Sketch a Maxwell–Boltzmann energy distribution for a fixed population at one temperature. On that same curve, mark the activation energies with and without a catalyst and shade the energetic fraction for each pathway. Explain the effect on rate and state what happens to the total area, mean molecular energy and equilibrium yield at this temperature. [6]

3.3 An exothermic reversible process gives the following experimental data at one pressure. The plant requires equilibrium yield at least 70% and measured production rate at least 0.50 mol min⁻¹. Select the only temperature meeting both conditions and use the numbers to reject each other temperature. Explain the opposed trends in yield and rate, then assess whether a catalyst at 650 K must restore the 450 K equilibrium yield. [6]

Temperature / K	Equilibrium yield / %	Measured production rate / mol min ⁻¹
450	92	0.040
550	76	0.60
650	46	2.5

Solutions

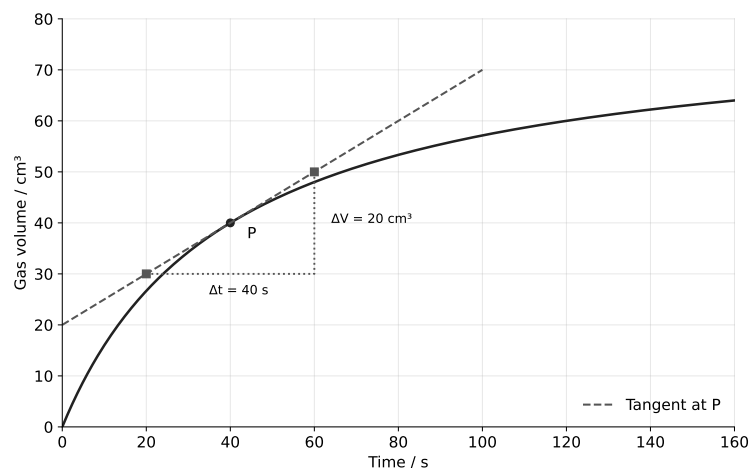
Original marking guidance: M1 method, A1 accuracy, B1 reasoning. Graph readings allow reasonable plotting variation.

2.1 More reactant particles per unit volume produce more frequent collisions with accessible catalyst/reactant sites. At the same temperature, the molecular energy distribution and mean kinetic energy remain the same; greater concentration alone does not imply hotter molecules.

2.2 More molecules per unit volume give more frequent collisions. At fixed temperature the energy distribution is unchanged, so the fraction above the unchanged threshold is unchanged. The precise rate–pressure relationship requires further experimental or kinetic information.

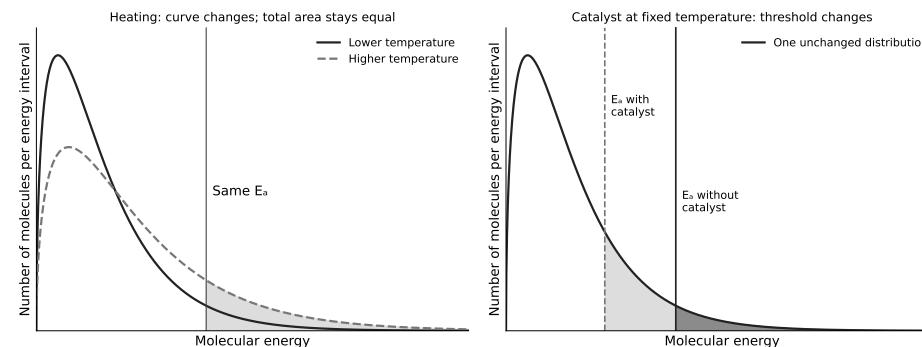
2.3 Energetic-fraction factor = $0.060/0.030 = 2.00$; total factor = $1.08 \times 2.00 = 2.16$. The doubled energetic fraction contributes more than the 8% frequency increase.

3.1



Straight local tangent at P; two separated points on the tangent, for example (20 s, 30 cm³) and (60 s, 50 cm³). Rate = $(50 - 30)/(60 - 20) = 0.50 \text{ cm}^3 \text{ s}^{-1}$. Origin-to-P gives $40/40 = 1.0 \text{ cm}^3 \text{ s}^{-1}$, an average over the first 40 s, rather than the slope at P.

3.2



Original marking guidance for the right panel: labelled axes and one valid distribution starting at the origin with a high-energy tail; lower catalysed threshold; correct nested areas to the right of each threshold. More collisions can exceed the lower threshold, increasing rate. Total area and mean energy are unchanged at this temperature. Equilibrium yield is unchanged; both reaction directions are accelerated.

3.3 550 K: $76\% \geq 70\%$ and $0.60 \geq 0.50 \text{ mol min}^{-1}$. At 450 K, $0.040 < 0.50$ despite its 92% yield; at 650 K, $46\% < 70\%$ despite its 2.5 mol min^{-1} rate. Heating favours the endothermic reverse direction and lowers product equilibrium yield, while a larger sufficiently energetic fraction increases reaction rate. A catalyst at 650 K leaves its equilibrium yield at 46%; it does not reproduce the 92% yield of 450 K. These data alone do not determine an economic optimum outside the stated requirements.