

## Solutions

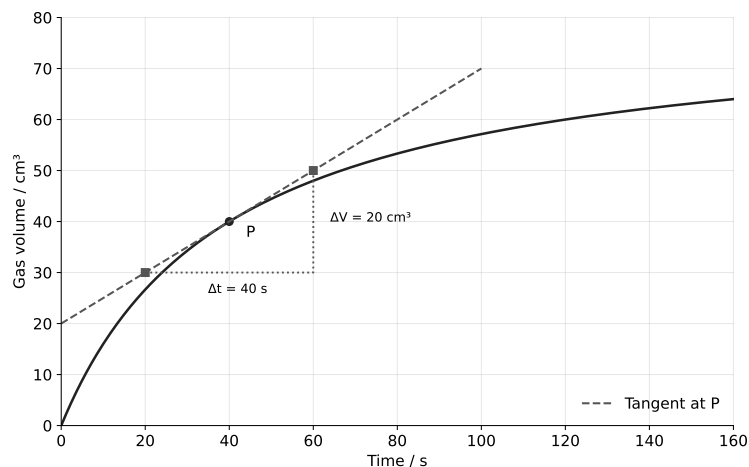
Original marking guidance: M1 method, A1 accuracy, B1 reasoning. Graph readings allow reasonable plotting variation.

**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.

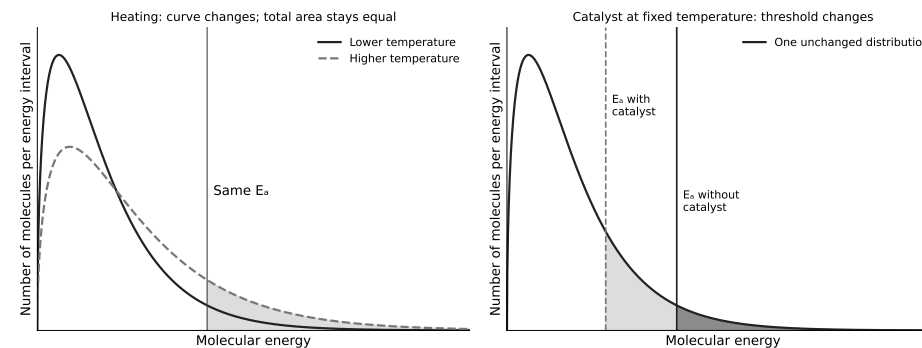
**2.3** Energetic-fraction factor =  $0.060/0.030 = 2.00$ ; total factor =  $1.08 \times 2.00 = 2.16$ . The doubled energetic fraction contributes more than the 8% frequency increase.

**3.1**



Straight local tangent at P; two separated points on the tangent, for example (20 s, 30 cm<sup>3</sup>) and (60 s, 50 cm<sup>3</sup>). 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  $2.5 \text{ mol min}^{-1}$  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.