Secondary 6 - Chemistry

Equilibrium, Rates and Gas Calculations

Name: _____

Class: _____

1. At room temperature and pressure, a data set shows that $0.0150\,\text{mol}$ of a gas occupies $0.360\,\text{dm}^3$. A $3.00\,\text{g}$ mixture of $\text{CaCO}_3(\text{s})$ and $\text{MgCO}_3(\text{s})$ is treated with excess hydrochloric acid. The resulting carbon dioxide occupies $0.816\,\text{dm}^3$ at the same conditions.
Given $M_r(\text{CaCO}_3) = 100$ and $M_r(\text{MgCO}_3) = 84$, what mass of CaCO_3 was in the mixture?

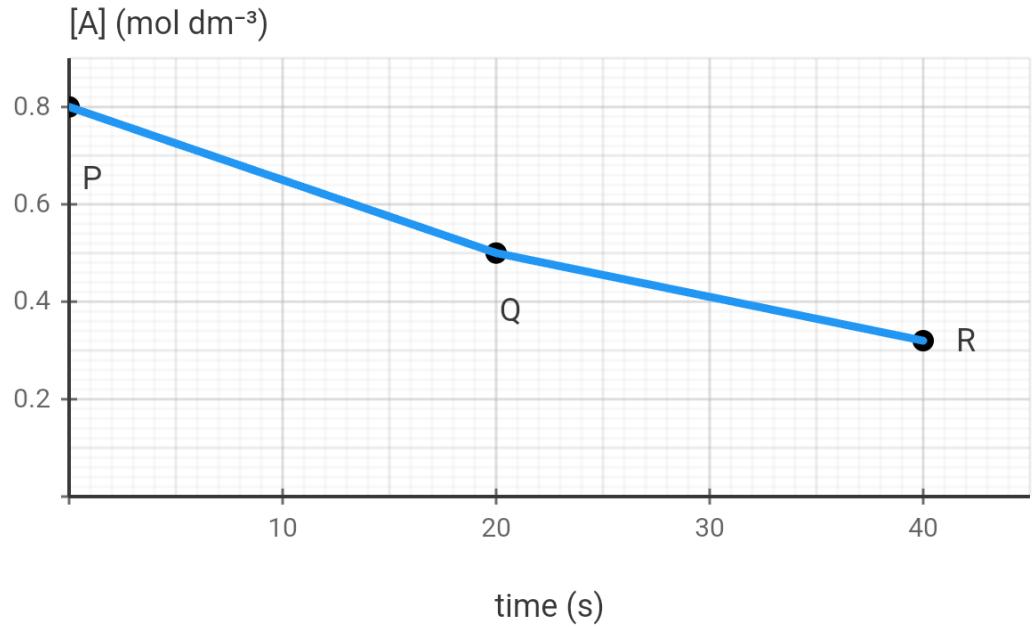
A. $0.600\,\text{g}$

B. $0.900\,\text{g}$

C. $1.50\,\text{g}$

D. $2.10\,\text{g}$

2. For the reaction $2\mathrm{A(aq)} \rightarrow \mathrm{B(aq)}$, the concentration-time graph below records the concentration of $\mathrm{A(aq)}$. The labelled readings are $P : (0\,\mathrm{s}, 0.80\,\mathrm{mol\,dm^{-3}})$, $Q : (20\,\mathrm{s}, 0.50\,\mathrm{mol\,dm^{-3}})$, and $R : (40\,\mathrm{s}, 0.32\,\mathrm{mol\,dm^{-3}})$.



What is the average rate of formation of $\mathrm{B(aq)}$ between $0\,\mathrm{s}$ and $40\,\mathrm{s}$?

A. $6.0 \times 10^{-3}\,\mathrm{mol\,dm^{-3}\,s^{-1}}$

B. $1.2 \times 10^{-2}\,\mathrm{mol\,dm^{-3}\,s^{-1}}$

C. $2.4 \times 10^{-2}\,\mathrm{mol\,dm^{-3}\,s^{-1}}$

D. $4.8 \times 10^{-1}\,\mathrm{mol\,dm^{-3}\,s^{-1}}$

3. In a sealed rigid vessel at constant temperature, the reaction $2\mathrm{NO(g)} + \mathrm{O_2(g)} \rightarrow 2\mathrm{NO_2(g)}$ occurs. $\mathrm{NO(g)}$ and $\mathrm{O_2(g)}$ are colourless, while $\mathrm{NO_2(g)}$ is brown.
Which measurements can be used to follow the progress of the reaction without opening the vessel?
(1) Colour intensity of the gas mixture
(2) Pressure of the vessel
(3) Mass of the sealed vessel and its contents

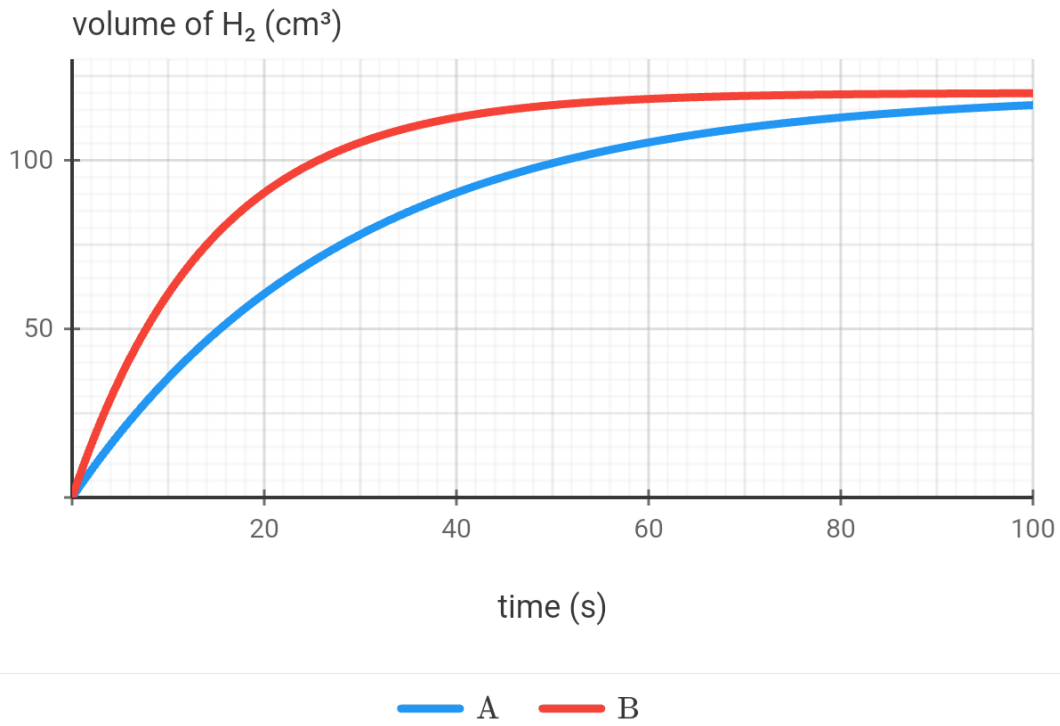
A. (1) and (2) only

B. (1) and (3) only

C. (2) and (3) only

D. (1), (2) and (3)

4. $0.327\,\mathrm{g}$ of zinc granules reacts with $100\,\mathrm{cm}^3$ of $1.0\,\mathrm{mol\,dm}^{-3}$ hydrochloric acid at room temperature and pressure, producing curve A below. Take $A_r(\mathrm{Zn}) = 65.4$ and the molar volume of a gas at room temperature and pressure as $24\,\mathrm{dm}^3\,\mathrm{mol}^{-1}$. Hydrochloric acid is in excess.



Which change could produce curve B?

A. Cool the reaction mixture by $10\,^\circ\mathrm{C}$.

B. Use $0.327\,\mathrm{g}$ of powdered zinc instead of zinc granules.

C. Use $0.164\,\mathrm{g}$ of zinc granules.

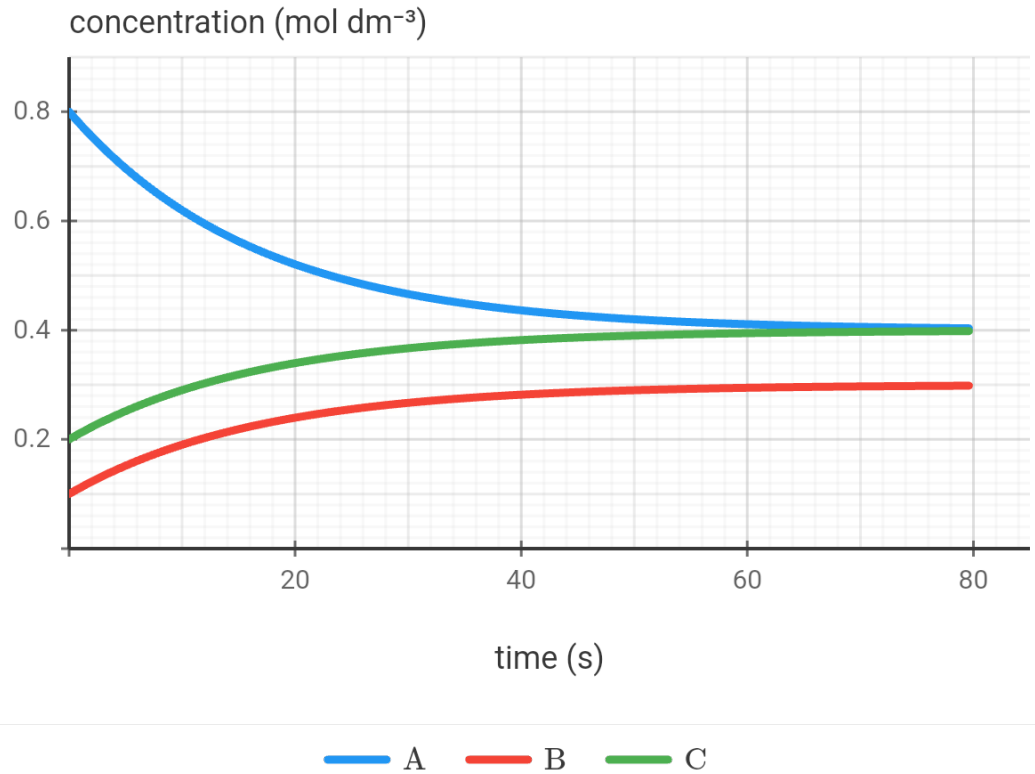
D. Use $100\,\mathrm{cm}^3$ of $0.050\,\mathrm{mol\,dm}^{-3}$ hydrochloric acid.

5. In a closed vessel at constant temperature, the concentration-time graph below is obtained for a reversible system involving $\mathrm{A(g)}$, $\mathrm{B(g)}$ and $\mathrm{C(g)}$. The initial and equilibrium readings are:

$[\mathrm{A}]_0 = 0.80\,\mathrm{mol\,dm^{-3}}$, $[\mathrm{A}]_{\mathrm{eq}} = 0.40\,\mathrm{mol\,dm^{-3}}$

$[\mathrm{B}]_0 = 0.10\,\mathrm{mol\,dm^{-3}}$, $[\mathrm{B}]_{\mathrm{eq}} = 0.30\,\mathrm{mol\,dm^{-3}}$

$[\mathrm{C}]_0 = 0.20\,\mathrm{mol\,dm^{-3}}$, $[\mathrm{C}]_{\mathrm{eq}} = 0.40\,\mathrm{mol\,dm^{-3}}$



Which equation can represent this reversible system?

A. $\mathrm{A(g)} \rightleftharpoons \mathrm{B(g)} + \mathrm{C(g)}$

B. $2\mathrm{A(g)} \rightleftharpoons \mathrm{B(g)} + \mathrm{C(g)}$

C. $\mathrm{A(g)} \rightleftharpoons 2\mathrm{B(g)} + \mathrm{C(g)}$

D. $\mathrm{B(g)} + \mathrm{C(g)} \rightleftharpoons 2\mathrm{A(g)}$

6. A reversible reaction is carried out in a closed vessel at fixed temperature. After equilibrium is attained, which statements are correct?
(1) The concentrations of the substances remain constant macroscopically.
(2) The forward and backward reactions continue at equal non-zero rates.
(3) Both the forward and backward reactions stop.
(4) The concentrations of all reactants and products are equal.

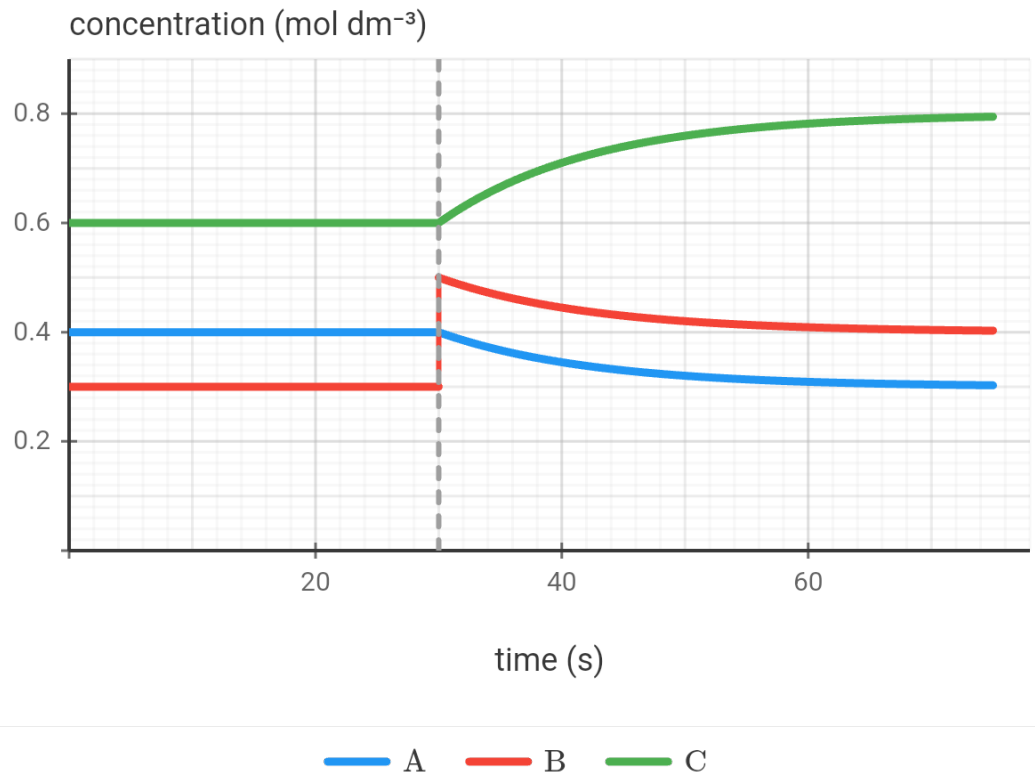
A. (1) and (2) only

B. (1) and (3) only

C. (2) and (4) only

D. (1), (2), (3) and (4)

7. At constant temperature, the system $\mathrm{A(g)} + \mathrm{B(g)} \rightleftharpoons 2\mathrm{C(g)}$ is initially at equilibrium in a closed container. At time t, a disturbance is applied. The dashed line in the graph marks time t.



Which change most likely occurred at time t?

A. A small amount of $\mathrm{A(g)}$ was removed.

B. A small amount of $\mathrm{B(g)}$ was added.

C. The container volume was increased.

D. A catalyst was added.

8. For the equilibrium $2\mathrm{SO_3(g)} \rightleftharpoons 2\mathrm{SO_2(g)} + \mathrm{O_2(g)}$, $K_c = 0.50\,\mathrm{mol\,dm^{-3}}$ at temperature T_1 and $K_c = 1.80\,\mathrm{mol\,dm^{-3}}$ at the higher temperature T_2. A mixture is at equilibrium at T_1 and is then heated rapidly to T_2 in a rigid closed vessel.
Which statement is correct immediately after heating and before the concentrations have had time to change?

A. K_c remains $0.50\,\mathrm{mol\,dm^{-3}}$, so the system remains at equilibrium.

B. K_c becomes $1.80\,\mathrm{mol\,dm^{-3}}$, while Q_c initially remains $0.50\,\mathrm{mol\,dm^{-3}}$; the system shifts right.

C. K_c becomes $1.80\,\mathrm{mol\,dm^{-3}}$, and Q_c immediately becomes $1.80\,\mathrm{mol\,dm^{-3}}$.

D. K_c decreases, so the system shifts left.

9. For the reaction $2\mathrm{X(g)} \rightleftharpoons \mathrm{Y(g)} + \mathrm{Z(g)}$, an equilibrium mixture in a $4.00\,\mathrm{dm^3}$ vessel contains $0.800\,\mathrm{mol}$ of X, $0.200\,\mathrm{mol}$ of Y and $0.400\,\mathrm{mol}$ of Z.
Which pair gives the equilibrium constant for the reaction as written and the equilibrium constant for its reverse reaction?

A. $K_c = 0.125$; reverse $K_c = 8.00$

B. $K_c = 0.125$; reverse $K_c = 0.0156$

C. $K_c = 8.00$; reverse $K_c = 0.125$

D. $K_c = 0.625$; reverse $K_c = 1.60$

10. The decomposition $2\mathrm{H_2O_2(aq)} \rightarrow 2\mathrm{H_2O(l)} + \mathrm{O_2(g)}$ is studied at the same temperature in two trials. The same mass of $\mathrm{MnO_2(s)}$ catalyst is used in each trial, and all other rate-relevant conditions are controlled.

Trial	Volume of $\mathrm{H_2O_2(aq)}$	Concentration of $\mathrm{H_2O_2(aq)}$
I	$40\,\mathrm{cm^3}$	$1.50\,\mathrm{mol\,dm^{-3}}$
II	$60\,\mathrm{cm^3}$	$1.00\,\mathrm{mol\,dm^{-3}}$

Which combination is correct?

A. Initial rate: Trial I is greater; final oxygen volume: equal in both trials.

B. Initial rate: Trial I is greater; final oxygen volume: Trial I is greater.

C. Initial rate: equal in both trials; final oxygen volume: equal in both trials.

D. Initial rate: equal in both trials; final oxygen volume: Trial II is greater.

Equilibrium, Rates and Gas Calculations

Answers

1 **B**

The molar volume at room temperature and pressure is deduced from the data:

$$V_m = \frac{0.360\,\text{dm}^3}{0.0150\,\text{mol}} = 24.0\,\text{dm}^3\,\text{mol}^{-1}$$

Thus, the amount of carbon dioxide formed is:

$$n(\text{CO}_2) = \frac{0.816\,\text{dm}^3}{24.0\,\text{dm}^3\,\text{mol}^{-1}} = 0.0340\,\text{mol}$$

Each carbonate produces one mole of carbon dioxide per mole. Let x be the amount of CaCO_3 and y be the amount of MgCO_3:

$$x + y = 0.0340$$

$$100x + 84y = 3.00$$

Substitute $y = 0.0340 - x$:

$$100x + 84(0.0340 - x) = 3.00$$

$$16x = 0.144$$

$$x = 0.00900\,\text{mol}$$

Therefore, the mass of calcium carbonate is:

$$m(\text{CaCO}_3) = 0.00900 \times 100 = 0.900\,\text{g}$$

2 **A**

First calculate the average rate of consumption of A using points P and R:

$$r_\text{A} = \frac{0.80 - 0.32}{40\,\text{s}} = \frac{0.48}{40\,\text{s}} = 0.0120\,\text{mol}\,\text{dm}^{-3}\,\text{s}^{-1}$$

The equation shows that 2 moles of A form 1 mole of B. Therefore, the formation rate of B is half the consumption rate of A:

$$r_\text{B} = \frac{1}{2}(0.0120) = 0.0060\,\text{mol}\,\text{dm}^{-3}\,\text{s}^{-1}$$

3 A

Colour intensity changes because brown $\mathrm{NO_2}$ is formed, so measurement (1) can follow the reaction.
The reaction changes the total amount of gas from 3 moles of gaseous reactants to 2 moles of gaseous product per stoichiometric event. Since the vessel has fixed volume and temperature, $pV = nRT$ shows that the pressure changes as the total gas amount changes. Therefore, measurement (2) is suitable.
The vessel is sealed, so no matter enters or leaves. Its total mass remains constant, making measurement (3) unsuitable for tracking progress.

4 B

The amount of zinc is:

$$n(\mathrm{Zn}) = \frac{0.327\,\mathrm{g}}{65.4\,\mathrm{g\,mol^{-1}}} = 0.00500\,\mathrm{mol}$$

The acid provides:

$$n(\mathrm{HCl}) = 1.0\,\mathrm{mol\,dm^{-3}} \times 0.100\,\mathrm{dm^3} = 0.100\,\mathrm{mol}$$

Only $0.0100\,\mathrm{mol}$ of hydrochloric acid is needed, so zinc is the limiting reactant. The final hydrogen volume is therefore fixed by the mass of zinc:

$$V(\mathrm{H_2}) = 0.00500 \times 24 = 0.120\,\mathrm{dm^3} = 120\,\mathrm{cm^3}$$

Using the same mass of powdered zinc increases the surface area in contact with the acid. The initial rate becomes greater, but the same amount of hydrogen is eventually formed, giving the same final volume.

5 B

The graph levels off, showing that the system reaches dynamic equilibrium: the concentrations become constant, although the forward and backward reactions continue.
From the initial and equilibrium readings:

$$\Delta[\mathrm{A}] = 0.40 - 0.80 = -0.40\,\mathrm{mol\,dm^{-3}}$$

$$\Delta[\mathrm{B}] = 0.30 - 0.10 = +0.20\,\mathrm{mol\,dm^{-3}}$$

$$\Delta[\mathrm{C}] = 0.40 - 0.20 = +0.20\,\mathrm{mol\,dm^{-3}}$$

The magnitude ratio is $0.40 : 0.20 : 0.20 = 2 : 1 : 1$. Since A is consumed while B and C are formed, the equation is:

$$2\mathrm{A(g)} \rightleftharpoons \mathrm{B(g)} + \mathrm{C(g)}$$

6 A

At dynamic equilibrium, the forward and backward reactions continue, but they occur at equal rates. Consequently, the macroscopic concentrations remain constant.
Statement (1) is correct because the concentrations no longer show an overall change.
Statement (2) is correct because equal forward and backward rates maintain the constant concentrations.
Statement (3) is incorrect: the reactions have not stopped; their rates are equal and non-zero.
Statement (4) is incorrect: equilibrium requires equal reaction rates, not equal concentrations. The actual concentrations depend on the equilibrium constant and the starting composition.

7 B

At time t, only the concentration of B shows an immediate upward jump. An immediate jump identifies the substance that was added.
After the jump, $[\mathrm{C}]$ increases while $[\mathrm{A}]$ and $[\mathrm{B}]$ decrease as the equilibrium shifts to the right. Therefore, the disturbance was the addition of a small amount of $\mathrm{B(g)}$.

8 B

Because the vessel is rigid and the mixture has not yet reacted further, the concentrations immediately after heating are unchanged. Therefore, the reaction quotient remains at its old equilibrium value:
$Q_c = 0.50\,\mathrm{mol\,dm^{-3}}$
However, the equilibrium constant depends on temperature, so at T_2:
$K_c = 1.80\,\mathrm{mol\,dm^{-3}}$
Thus, immediately after heating, $Q_c < K_c$. The forward reaction is favoured and the system shifts to the right, forming more $\mathrm{SO_2}$ and $\mathrm{O_2}$. The increase in K_c also indicates that the forward reaction is endothermic.

9 A

For the reaction as written, the equilibrium constant is:

$$K_c = \frac{[\mathrm{Y}][\mathrm{Z}]}{[\mathrm{X}]^2}$$

Convert each amount to concentration:

$$[\mathrm{X}] = \frac{0.800}{4.00} = 0.200\,\mathrm{mol\,dm^{-3}}$$

$$[\mathrm{Y}] = \frac{0.200}{4.00} = 0.0500\,\mathrm{mol\,dm^{-3}}$$

$$[\mathrm{Z}] = \frac{0.400}{4.00} = 0.100\,\mathrm{mol\,dm^{-3}}$$

Hence:

$$K_c = \frac{(0.0500)(0.100)}{(0.200)^2} = \frac{0.00500}{0.0400} = 0.125$$

Reversing an equation gives the reciprocal equilibrium constant:

$$K_{c,\,\mathrm{reverse}} = \frac{1}{0.125} = 8.00$$

10 A

The initial concentration is greater in Trial I:

$1.50\,\mathrm{mol\,dm^{-3}} > 1.00\,\mathrm{mol\,dm^{-3}}$

With the same temperature and catalyst mass, the greater reactant concentration gives Trial I the greater initial rate.

Now compare the total amounts of hydrogen peroxide:

$$n_{\mathrm{I}} = 1.50 \times 0.040 = 0.060\,\mathrm{mol}$$

$$n_{\mathrm{II}} = 1.00 \times 0.060 = 0.060\,\mathrm{mol}$$

Both trials therefore contain the same amount of limiting reactant. From the equation, 2 moles of hydrogen peroxide form 1 mole of oxygen:

$$n(\mathrm{O_2}) = \frac{0.060}{2} = 0.030\,\mathrm{mol}$$

Thus, the final volume of oxygen is the same in both trials, although Trial I reaches that final volume faster.