Begin your response to **QUESTION 2** on this page.

$$CH_3OH(g) \rightleftarrows CO(g) + 2\ H_2(g) \qquad \Delta H° = \ 90.0\ \text{kJ / mol}_{rxn}$$

2. Methanol vapor decomposes to form carbon monoxide gas and hydrogen gas at high temperatures in the presence of a platinum catalyst, as represented by the balanced chemical equation given.

(a) Are the hydrogen atoms oxidized or are they reduced in the forward reaction? Justify your answer in terms of oxidation numbers.

(b) In the following box, draw the complete Lewis electron-dot diagram for the carbon monoxide molecule in which every atom obeys the octet rule. Show all bonding and nonbonding valence electrons.

$$\boxed{\text{C} \quad \text{O}}$$

(c) The values of the standard molar entropies of the compounds involved in the reaction are given in the following table.

Substance	$S°$ (J/(K·mol))
$CH_3OH(g)$	240.
$CO(g)$	198
$H_2(g)$	131

(i) Use the data in the table to calculate the value of the standard entropy change, $\Delta S°$, in J/(K·mol$_{rxn}$), for the reaction.

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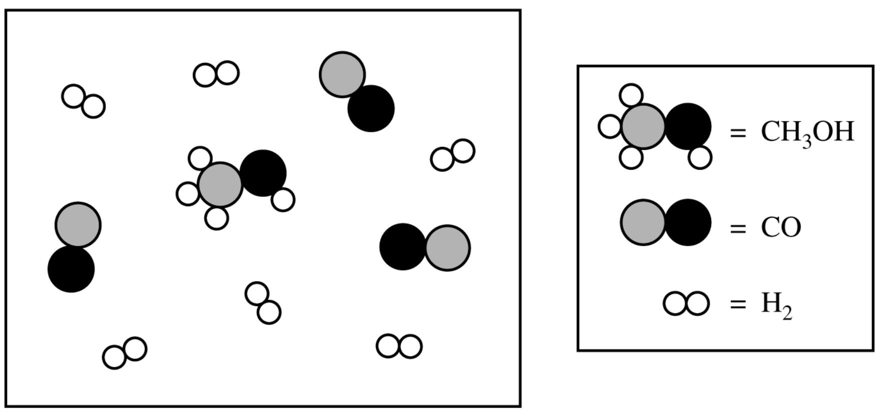
Continue your response to **QUESTION 2** on this page.

(ii) Calculate the value of $\Delta G°$, in kJ/mol_{rxn}, for the reaction at 375 K. Assume that $\Delta H°$ and $\Delta S°$ are independent of temperature.

The following particle-level diagram shows a representative sample of the equilibrium mixture represented by the equation given.



(d) Use information from the particle diagram to calculate the partial pressure of CO at equilibrium when the total pressure of the equilibrium mixture is 12.0 atm.

(e) Write the expression for the equilibrium constant, K_p, for the reaction.

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Continue your response to **QUESTION 2** on this page.

$$CH_3OH(g) \rightleftarrows CO(g) + 2\ H_2(g)$$

The reaction system represented by the equation is allowed to achieve equilibrium at a different temperature. The following table gives the partial pressure of each species in the equilibrium mixture.

Substance	Partial Pressure at Different Temperature
$CH_3OH(g)$	2.7 atm
$CO(g)$	4.2 atm
$H_2(g)$	8.4 atm

(f) Use the information in the table to calculate the value of the equilibrium constant, K_p, at the new temperature.

(g) The volume of the container is rapidly doubled with no change in temperature. As equilibrium is re-established, does the number of moles of $CH_3OH(g)$ increase, decrease, or remain the same? Justify your answer by comparing the value of the reaction quotient, Q, with the value of the equilibrium constant, K_p.

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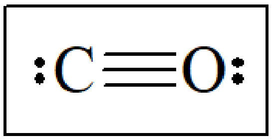
Question 2: Long Answer — 10 points

(a) For the correct answer and a valid justification: **1 point**

The H atoms are reduced because they change from an oxidation number of +1 to 0.

(b) For the correct answer: **1 point**



(c) (i) For the correct stoichiometry (may be implicit): **1 point**

$$\Delta S^\circ_{rxn} = \Sigma \Delta S^\circ_{products} - \Sigma \Delta S^\circ_{reactants}$$

$$\Delta S^\circ_{rxn} = \left(\Delta S^\circ_{CO(g)} + 2(\Delta S^\circ_{H_2(g)})\right) - \left(\Delta S^\circ_{CH_3OH(g)}\right)$$

For the correct calculated value: **1 point**

$$\Delta S^\circ_{rxn} = 198 + 2(131) - 240. = 220.\ \frac{\text{J}}{\text{K}\cdot\text{mol}_{rxn}}$$

(ii) For the correct calculated value: **1 point**

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

$$\Delta G^\circ = 90.0\ \frac{\text{kJ}}{\text{mol}_{rxn}} - (375\ \text{K})(0.220\ \frac{\text{kJ}}{\text{K}\cdot\text{mol}_{rxn}}) = +7.5\ \text{kJ/mol}_{rxn}$$

Total for part (c) — 3 points

(d) For the correct calculated value: **1 point**

$$P_{CO} = \frac{3}{10}(12.0\ \text{atm}) = 3.6\ \text{atm}$$

(e) For the correct expression: **1 point**

$$K_p = \frac{(P_{CO})(P_{H_2})^2}{(P_{CH_3OH})}$$

(f) For the correct calculated value: **1 point**

$$K_p = \frac{(P_{CO})(P_{H_2})^2}{(P_{CH_3OH})} = \frac{(4.2)(8.4)^2}{(2.7)} = 110$$

(g) For a correct comparison of Q and K: **1 point**

Accept one of the following:

- *The change in volume causes the partial pressure of each species to decrease by a factor of two. Because there are more moles of gaseous products than reactants, the decrease of the numerator in Q will be larger than that in the denominator, making* $Q_p < K_p$.
- $Q_p = \dfrac{\left(\dfrac{P_{CO}}{2}\right)\left(\dfrac{P_{H_2}}{2}\right)^2}{\left(\dfrac{P_{CH_3OH}}{2}\right)} = \dfrac{K_p}{4} \approx 27 < K_p$

For the correct answer and a valid justification: **1 point**

Decrease. Given that $Q_p < K_p$*, the partial pressures (moles) of the products will increase as equilibrium re-establishes, decreasing the number of moles of* CH_3OH.

Total for part (g) 2 points

Total for question 2 10 points