Q1.The following information concerns the equilibrium gas-phase synthesis of methanol.

$$
\mathrm{CO}(\mathrm{~g})+2 \mathrm{H}_{2}(\mathrm{~g}) \rightleftharpoons \mathrm{CH}_{3} \mathrm{OH}(\mathrm{~g})
$$

At equilibrium, when the temperature is $68^{\circ} \mathrm{C}$, the total pressure is 1.70 MPa . The number of moles of $\mathrm{CO}, \mathrm{H}_{2}$ and $\mathrm{CH}_{3} \mathrm{OH}$ present are $0.160,0.320$ and 0.180 , respectively.

Thermodynamic data are given below.

| Substance | $\Delta \boldsymbol{H}_{\mathbf{f}}^{\boldsymbol{\ominus}} / \mathbf{k J} \mathbf{~ m o l}^{-1}$ | $\boldsymbol{S}^{\boldsymbol{\ominus}} / \mathbf{J ~ K}^{\mathbf{1}} \mathbf{~ m o l}^{-1}$ |
| :---: | :---: | :---: |
| $\mathrm{CO}(\mathrm{g})$ | -110 | 198 |
| $\mathrm{H}_{2}(\mathrm{~g})$ | 0 | 131 |
| $\mathrm{CH}_{3} \mathrm{OH}(\mathrm{g})$ | -201 | 240 |

With pressures expressed in MPa units, the value of the equilibrium constant, $K_{\mathrm{p}}$, under these conditions is

A $\quad 1.37$
B 1.66
C $\quad 2.82$
D $\quad 4.80$
(Total 1 mark)

Q2.The following information concerns the equilibrium gas-phase synthesis of methanol.

$$
\mathrm{CO}(\mathrm{~g})+2 \mathrm{H}_{2}(\mathrm{~g}) \rightleftharpoons \mathrm{CH} 3 \mathrm{OH}(\mathrm{~g})
$$

At equilibrium, when the temperature is $68^{\circ} \mathrm{C}$, the total pressure is 1.70 MPa . The number of moles of $\mathrm{CO}, \mathrm{H}_{2}$ and $\mathrm{CH}_{3} \mathrm{OH}$ present are $0.160,0.320$ and 0.180 , respectively.

Thermodynamic data are given below.

| Substance | $\boldsymbol{\Delta} \boldsymbol{H}_{\mathbf{f}}^{\boldsymbol{\Theta}} / \mathbf{k J} \mathbf{~ m o l}^{-1}$ | $\mathbf{S}^{\boldsymbol{\Theta}} / \mathbf{J ~ K}^{\mathbf{1}} \mathbf{~ m o l}^{-1}$ |
| :---: | :---: | :---: |
| $\mathrm{CO}(\mathrm{g})$ | -110 | 198 |


| $\mathrm{H}_{2}(\mathrm{~g})$ | 0 | 131 |
| :---: | :---: | :---: |
| $\mathrm{CH}_{3} \mathrm{OH}(\mathrm{g})$ | -201 | 240 |

Which one of the following statements applies to this equilibrium?
A The value of $K_{\mathrm{p}}$ increases if the temperature is raised.
B $\quad$ The value of $K_{\mathrm{p}}$ increases if the pressure is raised.
C The yield of methanol decreases if the temperature is lowered.
D The yield of methanol decreases if the pressure is lowered.
(Total 1 mark)

Q3. Hydrogen and carbon monoxide were mixed in a $2: 1$ mole ratio. The mixture was allowed to reach equilibrium according to the following equation at a fixed temperature and a total pressure of $1.75 \times 10^{4} \mathrm{kPa}$.

$$
2 \mathrm{H}_{2}(\mathrm{~g})+\mathrm{CO}(\mathrm{~g}) \rightleftharpoons \mathrm{CH}_{3} \mathrm{OH}(\mathrm{~g})
$$

(a) The equilibrium mixture contained 0.430 mol of carbon monoxide and 0.0850 mol of methanol.
(i) Calculate the number of moles of hydrogen present in the equilibrium mixture.
$\qquad$
(ii) Hence calculate the mole fraction of hydrogen in the equilibrium mixture.
$\qquad$
$\qquad$
$\qquad$
(iii) Calculate the partial pressure of hydrogen in the equilibrium mixture.
$\qquad$
$\qquad$
(b) In a different mixture of the three gases at equilibrium, the partial pressure of carbon monoxide was 7550 kPa , the partial pressure of hydrogen was 12300 kPa and the partial pressure of methanol was 2710 kPa .
(i) Write an expression for the equilibrium constant, $K_{\mathrm{p}}$, for this reaction.
$\qquad$
(ii) Calculate the value of the equilibrium constant, $K_{p}$, for the reaction under these conditions and state its units.
$K_{\text {p }}$ $\qquad$
$\qquad$
Units $\qquad$
(c) Two isomeric esters $\mathbf{E}$ and $\mathbf{F}$ formed from methanol have the molecular formula $\mathrm{C}_{6} \mathrm{H}_{12} \mathrm{O}_{2}$

Isomer E has only 2 singlet peaks in its proton n.m.r. spectrum.
Isomer F is optically active.
Draw the structures of these two isomers.
Isomer E

Q4.

| Summarised directions for recording responses to multiple completion questions |  |  |  |
| :---: | :---: | :---: | :---: |
| A <br> (i), (ii) and (iii) <br> only | B <br> (i) and (iii) only | (ii) and (iv) only | (iv) alone |

Which of the following statements about a catalyst is / are true?
(i) It speeds up the forward reaction and slows down the reversere action.
(iii) It increases the proportion of molecules with higher energies.
(iii) A homogeneous catalyst usually acts in the solid state.
(iv) It does not alter the value of the equilibrium constant.

