AP® CHEMISTRY
2011 SCORING GUIDELINES (Form B)

Question 2
(9 points)

An 8.55 mol sample of methanol, CH_3OH, is placed in a 15.0 L evacuated rigid tank and heated to 327°C. At that temperature, all of the methanol is vaporized and some of the methanol decomposes to form carbon monoxide gas and hydrogen gas, as represented in the equation below.

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

(a) The reaction mixture contains 6.30 mol of $CO(g)$ at equilibrium at 327°C.

(i) Calculate the number of moles of $H_2(g)$ in the tank.

$6.30 \text{ mol CO} \times \frac{2 \text{ mol } H_2}{1 \text{ mol CO}} = 12.6 \text{ mol } H_2$	1 point is earned for the correct number of moles.

(ii) Calculate the number of grams of $CH_3OH(g)$ remaining in the tank.

$6.30 \text{ mol CO} \times \frac{1 \text{ mol } CH_3OH}{1 \text{ mol CO}} = 6.30 \text{ mol } CH_3OH \text{ reacted}$ $8.55 \text{ mol } CH_3OH_{initial} - 6.30 \text{ mol } CH_3OH_{reacted} = 2.25 \text{ mol } CH_3OH$ $2.25 \text{ mol} \times \frac{32.042 \text{ g}}{1 \text{ mol}} = 72.1 \text{ g}$	1 point is earned for the correct number of grams.

(iii) Calculate the mole fraction of $H_2(g)$ in the tank.

$\frac{12.6 \text{ mol } H_2}{2.25 \text{ mol } CH_3OH + 6.30 \text{ mol CO} + 12.6 \text{ mol } H_2}$ $= \frac{12.6}{21.15} = 0.596$	1 point is earned for the correct setup. 1 point is earned for the correct answer.

(iv) Calculate the total pressure, in atm, in the tank at 327°C.

$PV = nRT \Rightarrow P = \frac{nRT}{V}$ $= \frac{(21.15 \text{ mol})(0.0821 \frac{\text{L atm}}{\text{mol K}})(600 \text{ K})}{15.0 \text{ L}}$ $= 69.5 \text{ atm}$	1 point is earned for the correct setup. 1 point is earned for the correct answer.

Question 2 (continued)

(b) Consider the three gases in the tank at 327°C: $CH_3OH(g)$, $CO(g)$, and $H_2(g)$.

(i) How do the average kinetic energies of the molecules of the gases compare? Explain.

The average kinetic energies are the same because all three gases are at the same temperature.	1 point is earned for the correct answer and explanation.

(ii) Which gas has the highest average molecular speed? Explain.

$KE = \frac{1}{2}mv^2$, so at a given temperature the molecules with the lowest mass have the highest average speed. Therefore the molecules in H_2 gas have the highest average molecular speed.	1 point is earned for the correct answer and explanation.

(c) The tank is cooled to 25°C, which is well below the boiling point of methanol. It is found that small amounts of $H_2(g)$ and $CO(g)$ have dissolved in the liquid CH_3OH. Which of the two gases would you expect to be more soluble in methanol at 25°C? Justify your answer.

The only attractive forces between molecules of H_2 and CH_3OH would be due to weak London dispersion forces (LDFs). In contrast, the LDFs are stronger between CO molecules and CH_3OH molecules because CO has more electrons than H_2. In addition CO is slightly polar; thus intermolecular dipole-dipole attractions can form between CO molecules and CH_3OH molecules. With stronger intermolecular interactions between molecules of CO and CH_3OH, CO would be expected to be more soluble in CH_3OH than H_2.	1 point is earned for the correct answer and justification.