# Practice Test Questions 8
Effect of Temperature on Equilibrium

1. The two phase diagrams below are for two different noble gases. One is for neon and one is for xenon.

(a) Label the phases (solid/liquid/gas) on each diagram.

(b) Label the triple point on the diagram on the left.

(c) Label the critical point on the diagram on the right.

(d) Identify which diagram belongs to which noble gas. Briefly justify your answer using no more than one sentence.
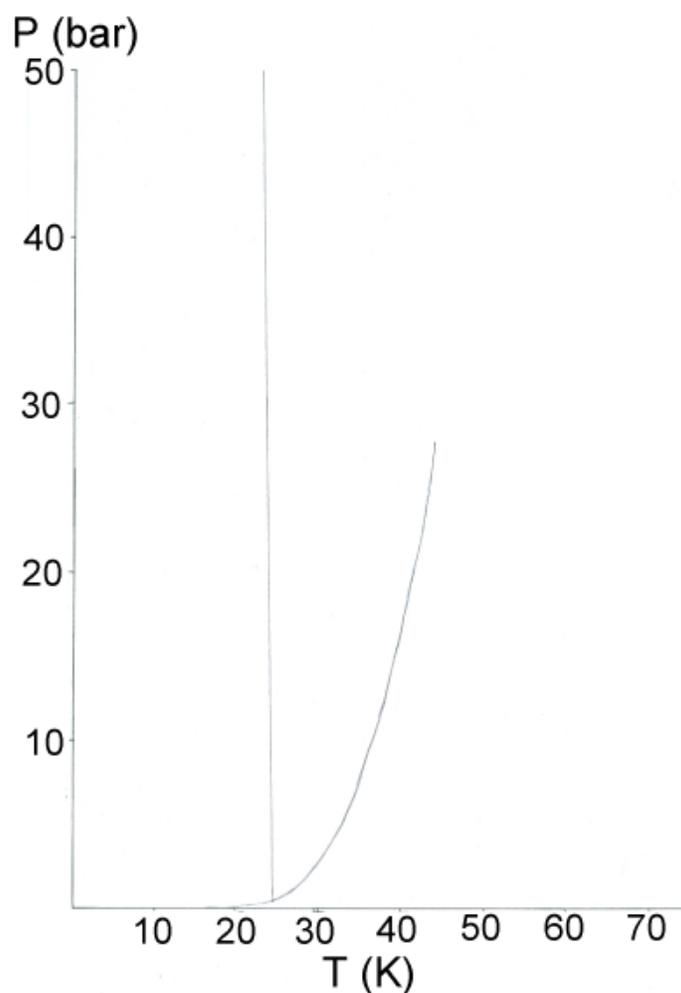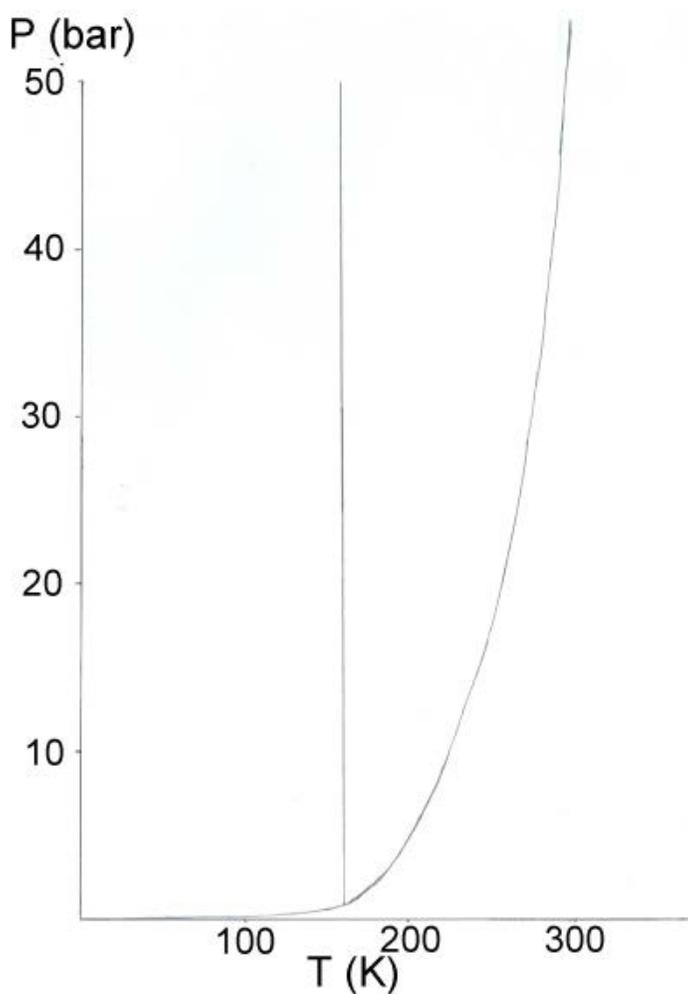
2.   Imagine that we take a gas at a temperature above its triple point temperature but below its critical point temperature and that we start to compress it at a constant temperature. Describe the sequence of changes which the substance would undergo as we increase the pressure.
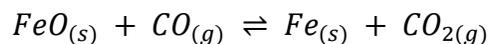
Your answer should include a labeled phase diagram.

3.   What is the vapour pressure of a solution made by dissolving 50 g of ammonium sulphate in 300 g of water at 40 °C? The vapour pressure of pure water at 40 °C is 7373 Pa.

4.   Benzene (C_6H_6) has an enthalpy of vaporization of 30.7 kJ/mol and a normal boiling point of 80.10 °C. The receiving flask of a typical vacuum filtration is at a pressure of 0.025 bar at room temperature. Will benzene boil under these conditions? *Justify your answer by calculating the boiling point of benzene at 0.025 bar.*
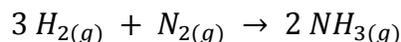
5.   Titanium tetrachloride ($TiCl_4$) is a liquid at room temperature. Estimate its normal boiling point. *Hint: Start by calculating the equilibrium constant for evaporation of $TiCl_4$ at 25 °C.*

6.   Consider the reaction below:
$$FeO_{(s)} + CO_{(g)} \rightleftharpoons Fe_{(s)} + CO_{2(g)}$$
The equilibrium constant for this reaction is 0.259 at 998 K. What is the equilibrium constant for this reaction at 298 K?

7.   You may recall from Chemistry 1000 that ammonia is synthesized industrially by the Haber-Bosch process. The balanced chemical equation for this process is
$$3\,H_{2(g)} + N_{2(g)} \rightarrow 2\,NH_{3(g)}$$
(a)   Calculate the equilibrium constant for this reaction at 25 °C.

(b)   In the industrial setting, the reaction is carried out at temperatures of 300 − 550 °C. The reaction is faster at higher temperatures. Estimate the equilibrium constant at 300 °C.

(c)   Why does the calculation in part (b) only give an estimate?

(d)   If the reaction is faster at higher temperatures, why don't all Haber-Bosch process plants operate at 550 °C? In other words, why do some plant operators prefer to operate at the lower end of the temperature range indicated above?

(e)   If the partial pressures of H_2, N_2 and NH_3 are, respectively, 150, 50 and 30 bar at 300 °C, is the reaction thermodynamically allowed?

8.   The following data were obtained for methane.

	temperature (K)	pressure (bar)
triple point	90.68	0.117
critical point	191	46.4
normal boiling point	112	
normal melting point	91	

(a)   Sketch a phase diagram for methane. On your diagram, you must label:

  • both axes

  • regions corresponding to the <u>four</u> states of matter discussed in class

Your sketch must be approximately to-scale. Use the graph paper below to help. *If you prefer, you may use the semi-logarithmic graph paper on the next page instead. Do not use both!*
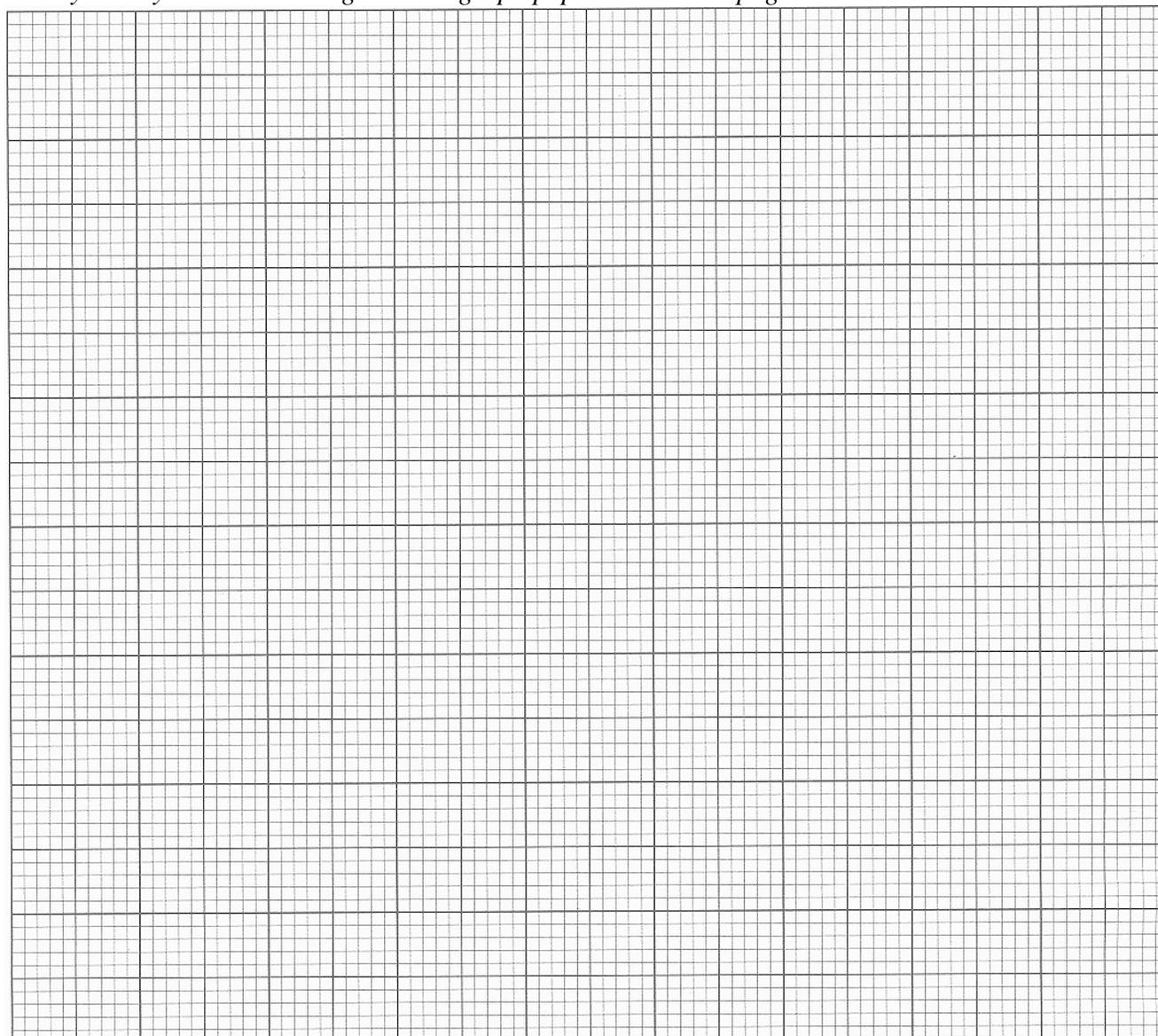
(b)   A sample of methane is initially at 20 K and 0.06 bar. The temperature is raised to 298 K while the pressure is maintained at 0.06 bar. What phase change will occur?

Alternate (semi-logarithmic) graph paper for question 5(a).
*If you draw two graphs for this answer, only the first (i.e. nonlogarithmic) will be marked.*
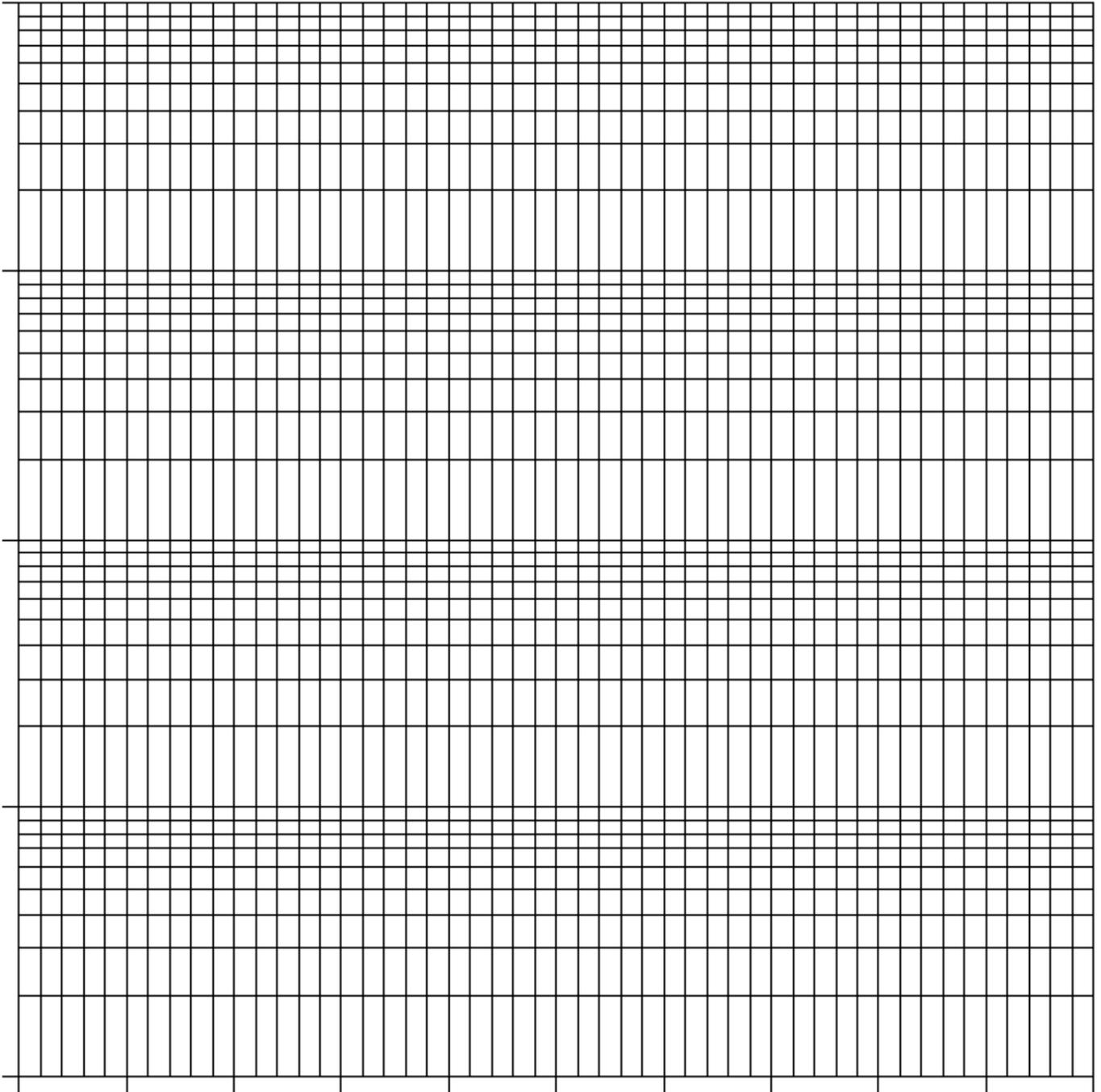
(b)   A sample of methane is initially at 20 K and 0.06 bar. The temperature is raised to 298 K while the pressure is maintained at 0.06 bar. What phase change will occur?

9. For each of the following statements, state whether it is TRUE or FALSE. **Briefly** explain the basis for your decision.

(a) Solutes decrease the boiling point of solutions compared to the pure solvent.

(b) The free energy of the system increases in a thermodynamically allowed process.

(c) Under standard conditions, Q = K.

10. A phase diagram for carbon dioxide is shown below:
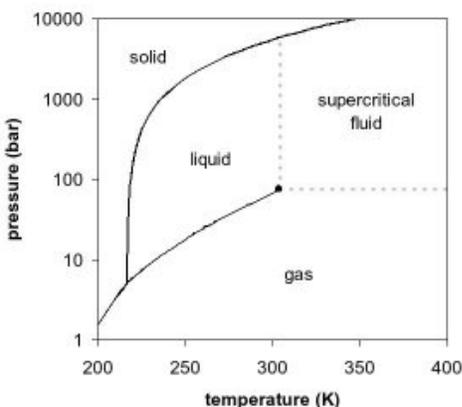
(a) On this diagram, divide the "gas" region into "ideal gas" and "nonideal gas" regions. *You will be marked on the relative positions of these regions not the absolute values.*

(b) What is a supercritical fluid? *Describe its physical properties.*

(c) i. Clearly mark and label the point on the diagram corresponding to 10 bar and 300 K.

   ii. What phase change(s) occur starting from this point if the pressure is maintained at 10 bar, but the temperature is decreased to 200 K?

   iii. Explain what is happening at the molecular level.

11. The Clausius-Clapeyron equation (shown below) relates vapour pressures (p_1 and p_2) for the same substance at different temperatures (T_1 and T_2).

$$\ln\left(\frac{p_2}{p_1}\right) = \frac{\Delta_r H^o}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

The Clausius-Clapeyron equation is very similar in appearance to the equation relating equilibrium constants for the same reaction:

$$\ln\left(\frac{K_2}{K_1}\right) = \frac{\Delta_r H^o}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

This is because the Clausius-Clapeyron equation can be derived from this second equation.

(a) What is vapour pressure?

(b) How does vapour pressure change as temperature increases? **Briefly**, explain why.

(c) Show how $\ln\left(\frac{p_2}{p_1}\right) = \frac{\Delta_r H^o}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$ can be derived from $\ln\left(\frac{K_2}{K_1}\right) = \frac{\Delta_r H^o}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$.

   Hint: Begin by writing a balanced chemical equation.
   You may use a generic substance (e.g. X) or choose any specific substance.

12.　Consider the following reaction in the gas phase:
$$2\,NOCl_{(g)} \rightleftharpoons 2\,NO_{(g)} + Cl_{2(g)}$$

(a)　Write the thermodynamic *equilibrium constant expression* for this reaction.

(b)　Calculate the equilibrium constant for this reaction *under standard conditions*.

(c)　Calculate the equilibrium constant for this reaction at 745 K.

(d)　A gas reactor is charged with 0.41 bar NO, 0.32 bar Cl_2 and 0.05 bar $NOCl$ at 745 K.　Determine whether the reaction will proceed in the forward or in the reverse reaction.

13.　The boiling point of pure water in Lethbridge (atmospheric pressure = 89.3 kPa) is 96.7 °C.

(a)　What is the vapor pressure of pure water in Lethbridge at 96.7 °C?

(b)　What is the vapor pressure of water of an aqueous solution prepared from 0.50 mol $MgCl_2$ and 1.000 kg of water at 96.7 °C in Lethbridge?

14.　In the gas phase, dinitrogen tetroxide $(N_2O_{4(g)})$ dissociates into $NO_{2(g)}$. At what temperature do you find 0.5 bar of N_2O_4 and 0.5 bar of NO_2 coexisting in equilibrium?
　　Hint: Start by calculating the equilibrium constant for the dissociation at exactly 25 °C.

15.　Carbon disulfide (CS_2) is a liquid at room temperature.

(a)　Calculate the vapor pressure for CS_2 at 25 °C.

(b)　Calculate the normal boiling point (the boiling point at 1 atm of ambient pressure) of CS_2.

16.

(a)　Calculate the vapour pressure of carbon tetrachloride (CCl_4) at exactly 25 °C.

(b)　Is CCl_4 a gas or a liquid at room temperature? Explain.

(c)　What is the vapour pressure of CCl_4 over a solution of 0.0200 kg of benzene (C_6H_6) dissolved in 0.250 kg of CCl_4?

17.　At 25 °C and 1.03 atm, carbon dioxide has a solubility of 0.0351 M in water.　What is its solubility at 25 °C and 2.24 atm?

18.

(a)　Calculate the pK_a value for $HCN_{(aq)}$ at exactly 25.00 °C from thermodynamics values.

(b)　Calculate the pK_a value for $HCN_{(aq)}$ at exactly 50.00 °C. Is HCN a stronger or weaker acid at 50.00 °C compared to 25.00 °C?

19.	Carbonic acid (H_2CO_3) is a diprotic acid.

(a)	Calculate K_a for dissociation of the first proton of $H_2CO_{3(aq)}$ at 25.00 °C.

(b)	Would the strength of this acid increase or decrease with temperature? Explain briefly.