## Chapter 17 Questions

## Section 17.1

1) Which of the following processes are spontaneous and which are nonspontaneous:
a) The melting of ice cubes at $-5^{\circ} \mathrm{C}$ and 1 atm.
b) Dissolution of sugar in a cup of hot coffee.
c) The reaction of nitrogen atoms to form $\mathrm{N}_{2}$ at $25^{\circ} \mathrm{C}$ and 1 atm .
d) Alignment of iron filings in a magnetic field
e) Formation of $\mathrm{CH}_{4}$ and $\mathrm{O}_{2}$ molecules from $\mathrm{CO}_{2}$ and $\mathrm{H}_{2} \mathrm{O}$ at room temperature and 1 atm.
f) Water flowing up hill
g) A fire spreading in a purely nitrogen environment.
2) A $19^{\text {th }}$ Century chemist suggested that all chemical processes that proceed spontaneously are exothermic. Is this correct?

3a) What is another term for a thermodynamically favorable process?
b) What is another term for a process that is not thermodynamically favorable?

4a) What is meant by calling a process irreversible?
b) After an irreversible process, the system is restored to its original state. What can be said about the restoration process?

## Sections 17.2 \& 17.5

6a) Describe a process for which the entropy of the system decreases.
b) What is the sign of $\Delta \mathrm{S}$ for the process in part (a)?

7a) In a chemical reaction, two moles of gaseous reactants are converted into 3 moles of gaseous products. Predict the sign of $\Delta \mathrm{S}$.
b) In a chemical reaction, two gases combine to form a solid. Predict the sign of $\Delta \mathrm{S}$.

8a) Express the second law of thermodynamics in your own words.
b) If the entropy of the system increases during a reversible process, what can you say about the entropy change of the surroundings?

9a) State the third law of thermodynamics in your own words.
b) What is the difference between translational motion, vibrational motion and rotational motion of a molecule?
5) The normal freezing point of hexane is -95 ${ }^{\circ} \mathrm{C}$.
a) Is the freezing of hexane an endothermic or exothermic process?
b) Is the melting of hexane an endothermic or exothermic process?
c) In what temperature range is the freezing of hexane a spontaneous process?
d) In what temperature range is it a nonspontaneous process?
e) Is there any temperature at which liquid and solid hexane are in equilibrium? Explain.
f) Is this melting/freezing process of hexane reversible or irreversible? Explain.
6) A system goes from State 1 to State 2 and back to State 1. What is the relationship between the value of $\Delta \mathrm{E}$ for going from State 1 to State 2 to that for going from State 2 back to State 1?
7) A small amount of a toxic gas is released in a room. Describe the process in terms of reversibility and spontaneity.
10) Predict the sign of entropy change for the system in each of the following reactions:
a) $2 \mathrm{SO}_{2}(\mathrm{~g})+\mathrm{O}_{2}(\mathrm{~g})-->2 \mathrm{SO}_{3}(\mathrm{~g})$
b) $\mathrm{Ba}(\mathrm{OH})_{2}(\mathrm{~s})-->\mathrm{BaO}(\mathrm{s})+\mathrm{H}_{2} \mathrm{O}(\mathrm{g})$
c) $\mathrm{CO}(\mathrm{g})+2 \mathrm{H}_{2}(\mathrm{~g})-->\mathrm{CH}_{3} \mathrm{OH}(\mathrm{l})$
d) $\mathrm{FeCl}_{2}(\mathrm{~s})+\mathrm{H}_{2}(\mathrm{~g})-->\mathrm{Fe}(\mathrm{s})+2 \mathrm{HCl}(\mathrm{g})$
e) $\mathrm{BaCl}_{2}(\mathrm{aq})+\mathrm{Na}_{2} \mathrm{SO}_{4}(\mathrm{aq})$--> $2 \mathrm{NaCl}(\mathrm{aq})+\mathrm{BaSO}_{4}$ (s)
f) $2 \mathrm{NOCl}(\mathrm{g})$--> $2 \mathrm{NO}(\mathrm{g})+\mathrm{Cl}_{2}(\mathrm{~g})$
11) For each of the following pairs, indicate which substance possesses the larger standard entropy:
a) 1 mol of $\mathrm{O}_{2}$ at $0^{\circ} \mathrm{C}$ and 1 atm or 1 mol of $\mathrm{O}_{2}$ at $200^{\circ} \mathrm{C}$ and 1 atm
b) $\mathrm{He}(\mathrm{g})$ at 3 atm pressure or at 1.5 atm pressure
c) 0.5 mol of $\mathrm{N}_{2}$ at 298 K and 20 L volume or 0.5 mol of $\mathrm{N}_{2}$ at 298 K and 40 L volume
d) $100 \mathrm{~g} \mathrm{Na}_{2} \mathrm{SO}_{4}$ (s) at $30^{\circ} \mathrm{C}$ or $100 \mathrm{~g} \mathrm{Na}{ }_{2} \mathrm{SO}_{4}$ (aq) at $30^{\circ} \mathrm{C}$
e) 1 mol of $\mathrm{CO}_{2}(\mathrm{~g})$ at STP or 1 mol of $\mathrm{O}_{2}(\mathrm{~g})$ at STP f) Equal volume of $1.0 \mathrm{M} \mathrm{NaCl}(a q)$ or $1.0 \mathrm{M} \mathrm{K}_{2} \mathrm{SO}_{4}$ (aq)
12) Using Appendix 4, compare the standard enthalpies at $25^{\circ} \mathrm{C}$ for the following pairs. For each pair, explain the difference in entropy.
a) $\mathrm{I}_{2}(\mathrm{~g})$ and $\mathrm{I}_{2}(\mathrm{~s})$
b) $1 \mathrm{~mol} \mathrm{~N}_{2} \mathrm{O}_{4}(\mathrm{~g})$ and $2 \mathrm{~mol} \mathrm{NO}_{2}(\mathrm{~g})$
c) $1 \mathrm{~mol} \mathrm{MgCO}_{3}(\mathrm{~s})$ and $[1 \mathrm{~mol} \mathrm{MgO}$ (s) plus 1 $\left.\mathrm{mol} \mathrm{CO}_{2}(\mathrm{~g})\right]$
d) 1 mol NaCl (s) and [1 mol $\mathrm{Na}^{+}$(aq) plus 1 mol $\mathrm{Cl}(\mathrm{aq})]$
e) $1 \mathrm{~mol} \mathrm{HBr}(\mathrm{g})$ and $1 \mathrm{~mol} \mathrm{HCl}(\mathrm{g})$
13) Use Appendix 4 to compare the absolute entropies of the following gaseous
hydrocarbons: methane $\left(\mathrm{CH}_{4}\right)$, ethane $\left(\mathrm{C}_{2} \mathrm{H}_{6}\right)$, propane $\left(\mathrm{C}_{3} \mathrm{H}_{8}\right)$ and butane $\left(\mathrm{C}_{4} \mathrm{H}_{10}\right)$. What do you conclude about the trends in $\mathrm{S}^{\circ}$ as the number of carbon atoms increase?
14) Using $S^{\circ}$ values from Appendix 4. calculate the $\Delta \mathrm{S}^{\circ}$ values for the following reactions:
a) $\mathrm{C}_{2} \mathrm{H}_{4}(\mathrm{~g})+\mathrm{H}_{2}(\mathrm{~g})-->\mathrm{C}_{2} \mathrm{H}_{6}(\mathrm{~g})$
b) $\mathrm{N}_{2} \mathrm{O}_{4}(\mathrm{~g})-->2 \mathrm{NO}_{2}(\mathrm{~g})$
c) $\mathrm{Be}(\mathrm{OH})_{2}$ (s) $-->\mathrm{BeO}(\mathrm{s})+\mathrm{H}_{2} \mathrm{O}$ (g)
d) $2 \mathrm{CH}_{3} \mathrm{OH}(\mathrm{g})+3 \mathrm{O}_{2}(\mathrm{~g})$-->

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2 \mathrm{CO}_{2}(\mathrm{~g})+4 \mathrm{H}_{2} \mathrm{O}(\mathrm{~g})
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18) From the values given for $\Delta \mathrm{H}^{\circ}$ and $\Delta \mathrm{S}^{\circ}$, calculate $\Delta \mathrm{G}^{\circ}$ for each of the following reactions at 298 K . If the reaction is not spontaneous under standard conditions at 298 K , at what temperature (if any) would the reaction be spontaneous?
a) $2 \mathrm{PbS}(\mathrm{s})+3 \mathrm{O}_{2}(\mathrm{~g})-->2 \mathrm{PbO}(\mathrm{s})+2 \mathrm{SO}_{2}(\mathrm{~g})$, $\Delta \mathrm{H}^{\mathrm{O}}=-844 \mathrm{~kJ}, \Delta \mathrm{~S}^{\mathrm{O}}=-165 \mathrm{~J} / \mathrm{K}$
b) $\mathrm{N}_{2}(\mathrm{~g})+3 \mathrm{Cl}_{2}(\mathrm{~g})-->2 \mathrm{NCl}_{3}(\mathrm{~g}), \Delta \mathrm{H}^{\mathrm{O}}=460 \mathrm{~kJ}$, $\Delta S^{\circ}=-275 \mathrm{~J} / \mathrm{K}$

19a) A particular reaction is spontaneous at 450 K . The reaction is endothermic by 34.5 kJ . What can you conclude about the sign and magnitude of $\Delta \mathrm{S}$ for the reaction?
b) Another reaction is not thermodynamically favorable at 45 OC. The entropy change for the reaction is $72 \mathrm{~J} / \mathrm{K}$. What can you conclude about the sign and magnitude of $\Delta H$ ?
20) For a particular reaction, $\Delta \mathrm{H}=-32 \mathrm{~kJ}$ and $\Delta \mathrm{S}=-98 \mathrm{~J} / \mathrm{K}$. Assume that $\Delta \mathrm{H}$ and $\Delta \mathrm{S}$ do not vary with temperature.
a) At what temperature will the reaction have $\Delta \mathrm{G}=0$ ?
b) If T is increased from that point, will the reaction be spontaneous or nonspontaneous?

## Section 17.7 \& 17.8

21) Indicate whether $\Delta \mathrm{G}$ increases, decreases or does not change when the partial pressure of $\mathrm{H}_{2}$ is increased in each of the following reactions:
a) $\mathrm{N}_{2}(\mathrm{~g})+3 \mathrm{H}_{2}(\mathrm{~g})<==>2 \mathrm{NH}_{3}(\mathrm{~g})$
b) $2 \mathrm{HBr}(\mathrm{g})<==>\mathrm{H}_{2}(\mathrm{~g})+\mathrm{Br}_{2}(\mathrm{~g})$
c) $2 \mathrm{H}_{2}(\mathrm{~g})+\mathrm{C}_{2} \mathrm{H}_{2}(\mathrm{~g})<==>\mathrm{C}_{2} \mathrm{H}_{6}(\mathrm{~g})$
d) $\mathrm{H}_{2}(\mathrm{~g})+\mathrm{F}_{2}(\mathrm{~g})<==>2 \mathrm{HF}(\mathrm{g})$
e) $\mathrm{C}_{2} \mathrm{H}_{6}(\mathrm{~g})<==>2 \mathrm{C}(\mathrm{s})+3 \mathrm{H}_{2}(\mathrm{~g})$

22a) At 300 K , the reaction

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\mathrm{N}_{2}(\mathrm{~g})+3 \mathrm{H}_{2}(\mathrm{~g})<==>2 \mathrm{NH}_{3}(\mathrm{~g}),
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$K_{p}=9.60$. What is the value of $\Delta G$ ?
b) A reaction at $20^{\circ} \mathrm{C}$ has a free energy of +12.6
$\mathrm{kJ} / \mathrm{mol}$. What is the $\mathrm{K}_{\mathrm{p}}$ ?
c) At equilibrium, the reaction
$2 \mathrm{NO}(\mathrm{g})+\mathrm{Cl}_{2}(\mathrm{~g})<==>2 \mathrm{NOCl}(\mathrm{g})$
has $\mathrm{P}_{\mathrm{NO}}=0.095 \mathrm{~atm}, \mathrm{P}_{\mathrm{Cl} 2}=0.171 \mathrm{~atm}$ and
$\mathrm{P}_{\mathrm{NOCl}}=0.28 \mathrm{~atm}$. What is the $\Delta \mathrm{G}$ for the reaction?
23) Consider the reaction $2 \mathrm{NO}_{2}(\mathrm{~g}) \leftrightarrows \mathrm{N}_{2} \mathrm{O}_{4}(\mathrm{~g})$. a) Using data from Appendix 4, calculate $\Delta \mathrm{G}^{\mathrm{O}}$ at 298 K.
b) Calculate $\Delta \mathrm{G}$ at 298 K if the partial pressure of $\mathrm{NO}_{2}$ and $\mathrm{N}_{2} \mathrm{O}_{4}$ are 0.40 atm and 1.60 atm , respectively.
24) Calculate the $\Delta G$ for the reaction $\mathrm{H}_{2}(\mathrm{~g})+\mathrm{F}_{2}(\mathrm{~g})$--> $2 \mathrm{HF}(\mathrm{g})$
at 700 K and when the pressures for the gases are $0.30 \mathrm{~atm}, 0.50 \mathrm{~atm}$ and 1.2 atm for $\mathrm{H}_{2}, \mathrm{~F}_{2}$ and $H F$, respectively.
d) $\mathrm{P}_{4} \mathrm{O}_{10}$ (s) $+6 \mathrm{H}_{2} \mathrm{O}$ (l) --> $4 \mathrm{H}_{3} \mathrm{PO}_{4}$ (aq)
25) Use data from Appendix 4 to calculate $K_{p}$ at 298 K for each of the following reactions:
a) $\mathrm{H}_{2}(\mathrm{~g})+\mathrm{Br}_{2}(\mathrm{~g}) \leftrightarrows 2 \mathrm{HBr}(\mathrm{g})$
b) $\mathrm{C}_{2} \mathrm{H}_{5} \mathrm{OH}(\mathrm{l}) \leftrightarrows \mathrm{C}_{2} \mathrm{H}_{4}(\mathrm{~g})+\mathrm{H}_{2} \mathrm{O}(\mathrm{l})$
c) $\mathrm{C}_{2} \mathrm{H}_{2}(\mathrm{~g})+\mathrm{H}_{2} \mathrm{O}(\mathrm{g}) \leftrightarrows \mathrm{C}_{2} \mathrm{H}_{4} \mathrm{O}(\mathrm{g})$

## Review

The methane, $\mathrm{CH}_{4}$, that escapes from a gas jet comes out at a rate of 2 CFM (cubic feet per minute). The methane gas is measured to have a temperature of $19{ }^{\circ} \mathrm{C}$ coming out of the jet in a classroom that has an atmospheric pressure of 98.6 kPa . Assume ideal conditions for the gas. Suppose the methane is used to directly heat a 500 g piece of copper metal (specific heat $=0.380 \mathrm{~J} / \mathrm{gK}$ ) for 30 seconds.

1) What is the density of the methane gas in the room?
2) How much heat is generated by the combustion of methane $\left(\Delta \mathrm{H}_{\mathrm{rxn}}=-890 \mathrm{~kJ}\right)$ ?
3) Assuming that $70 \%$ of the heat generated is absorbed by the copper, what is the final temperature of the copper?
4) The combustion of the methane produces how many grams of carbon dioxide? How many liters at lab conditions?
