NOW WITH SOLUTIONS!

15.1. Which of the following is not part of the equilibrium constant expression, K_c?
A) Solids B) Liquids C) Dissolved species D) A and B E) B and C

15.2. Which is the correct equilibrium constant expression for the following reaction?

$$FeO(s) + H_2(g) \rightleftharpoons Fe(s) + H_2O(g)$$

A) $K_c = [H_2O] / [H_2]$
B) $K_c = [Fe] [H_2O] / [Fe_2O_3]$
C) $K_c = [Fe_2O_3] [H_2] / [Fe][H_2O]$
D) $K_c = [Fe][H_2O] / [Fe_2O_3] [H_2]$
E) $K_c = [H_2] / [H_2O]$

15.3. The equilibrium constant expression for the reaction
$2BrCl_3(g) \rightleftharpoons Br_2(g) + 3Cl_2(g)$ is
A) $K_c =[Br_2] [Cl_2] / [BrCl_3]$
B) $K_c = [Br_2] [Cl_2]^5 / [BrCl_3]^2$
C) $K_c = [Br_2] [Cl_2]^3 / [BrCl_3]^2$
D) $K_c = [BrCl_3]^2 / [Br_2][Cl_2]^3$
E) $K_c = 2[BrCl_3]^2 / ([Br_2] \times 3[Cl_2]^3)$

15.4. Carbon tetrachloride reacts at high temperatures with oxygen to produce two toxic gases, phosgene and chlorine.
$CCl_4(g) + (1/2)O_2(g) \rightleftharpoons COCl_2(g) + Cl_2(g)$, $K_c = 4.4 \times 10^9$ at 1,000 K
Calculate K_c for the reaction $2CCl_4(g) + O_2(g) \rightleftharpoons 2COCl_2(g) + 2Cl_2(g)$.
A) 4.4×10^9 B) 8.8×10^9 C) 1.9×10^{10} D) 1.9×10^{19} E) 2.3×10^{-10}

15.5. 1.75 moles of H_2O_2 were placed in a 2.50 L reaction chamber at 307°C. After equilibrium was reached, 1.20 moles of H_2O_2 remained. Calculate the equilibrium constant, K_c, for the reaction $2H_2O_2(g) \rightleftharpoons 2H_2O(g) + O_2(g)$.
A) 2.0×10^{-4} B) 2.3×10^{-2} C) 2.4×10^{-3} D) 5.5×10^{-3} E) 3.9×10^{-4}

15.6. Consider the reversible reaction: $2NO_2(g) \rightleftharpoons N_2O_4(g)$
If the concentrations of both NO_2 and N_2O_4 are 0.016 mol L^{-1}, what is the value of Q_c?
A) 0.016 B) 0.50 C) 1.0 D) 2.0 E) 63

15.7. A mixture 0.500 mole of carbon monoxide and 0.400 mole of bromine was placed into a rigid 1.00-L container and the system was allowed to come to equilibrium. The equilibrium concentration of $COBr_2$ was 0.233 *M*. What is the value of K_c for this reaction?

$$CO(g) + Br_2(g) \rightleftharpoons COBr_2(g)$$

A) 5.23 B) 1.22 C) 1.165 D) 0.858 E) 0.191

15.8. At 25°C, the equilibrium constant K_c for the reaction

$$2A(g) \rightleftharpoons B(g) + C(g)$$

is 0.035. A mixture of 8.00 moles of B and 12.00 moles of C in a 20.0 L container is allowed to come to equilibrium. What is the equilibrium concentration of A?
A) < 0.100 *M* B) 0.339 *M* C) 0.678 *M* D) 6.78 *M* E) 13.56 *M*

15.9. Consider the equilibrium reaction: $N_2O_4(g) \rightleftharpoons 2NO_2(g)$

Which of the following correctly describes the relationship between K_c and K_p for the reaction?

A) $K_p = K_c$

B) $K_p = RT \times K_c$

C) $K_p = (RT \times K_c)^{-1}$

D) $K_p = K_c / RT$

E) $K_p = RT/K_c$

15.10. The equilibrium constant, K_p, has a value of 6.5×10^{-4} at 308 K for the reaction of nitrogen monoxide with chlorine.

$$2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g)$$

What is the value of K_c?

A) 2.5×10^{-7}

B) 6.5×10^{-4}

C) 1.6×10^{-2}

D) 1.7

E) None of these choices is correct.

15.11. The reaction of nitrogen with oxygen to form nitrogen monoxide can be represented by the following equation.

$$N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$$

At 2000°C, the equilibrium constant, K_c, has a value of 4.10×10^{-4}. What is the value of K_p?

A) 2.17×10^{-8}

B) 4.10×10^{-4}

C) 7.65×10^{-2}

D) 7.75

E) None of these choices is correct.

15.12. At 850°C, the equilibrium constant K_p for the reaction

$$C(s) + CO_2(g) \rightleftharpoons 2CO(g)$$

has a value of 10.7. If the total pressure in the system at equilibrium is 1.000 atm, what is the partial pressure of carbon monoxide?

A) 0.362 atm B) 0.489 atm C) 0.667 atm D) 0.915 atm E) 0.921 atm

15.13. Hydrogen iodide decomposes according to the equation $2HI(g) \leftrightharpoons H_2(g) + I_2(g)$, for which $K_c = 0.0156$ at 400°C. 0.550 mol HI was injected into a 2.00 L reaction vessel at 400°C. Calculate the concentration of HI at equilibrium.

A) 0.138 M B) 0.220 M C) 0.550 M D) 0.275 M E) 0.0275 M

15.14. For the following reaction at equilibrium, which choice gives a change that will shift the position of equilibrium to favor formation of more products?

$$2NOBr(g) \leftrightharpoons 2NO(g) + Br_2(g), \quad \Delta H^\circ_{rxn} = 30 \text{ kJ/mol}$$

A) Increase the total pressure by decreasing the volume.

B) Add more NO.

C) Remove Br_2.

D) Lower the temperature.

E) Remove NOBr selectively.

15.15. For the following reaction at equilibrium, which one of the changes below would cause the equilibrium to shift to the *left*?

$$2NOBr(g) \rightleftharpoons 2NO(g) + Br_2(g), \quad \Delta H^\circ_{rxn} = 30 \text{ kJ/mol}$$

A) Increase the container volume.
B) Remove some NO.
C) Remove some Br_2.
D) Add more NOBr.
E) Decrease the temperature.

14.1 Butadiene, C_4H_6 (used to make synthetic rubber and latex paints) dimerizes to C_8H_{12} with a rate law of rate = 0.014 L/(mol·s) $[C_4H_6]^2$. What will be the concentration of C_4H_6 after 3.0 hours if the initial concentration is 0.025 *M*?

A) 0.0052 *M* B) 0.024 *M* C) 43 *M* D) 190 *M* E) 0.0000 *M*

14.2 What is the slope of a plot of ln k vs. 1/T for the Arrhenius equation $k=Ae^{-(Ea/RT)}$?

A) A B) -k C) $-E_a/R$ D) k E) E_a

14.3 The following initial rate data apply to the reaction

$$F_2(g) + 2Cl_2O(g) \rightarrow 2FClO_2(g) + Cl_2(g).$$

Expt. #	$[F_2]$ (M)	$[Cl_2O]$ (M)	Initial rate (M/s)
1	0.05	0.010	5.0×10^{-4}
2	0.05	0.040	2.0×10^{-3}
3	0.10	0.010	1.0×10^{-3}

Which of the following is the rate law (rate equation) for this reaction?

A) rate = $k[F_2]^2[Cl_2O]^4$
B) rate = $k[F_2]^2[Cl_2O]$
C) rate = $k[F_2][Cl_2O]$
D) rate = $k[F_2][Cl_2O]^2$
E) rate = $k[F_2]^2[Cl_2O]^2$

14.4 The thermal decomposition of acetaldehyde, $CH_3CHO \rightarrow CH_4 + CO$, is a second-order reaction. The following data were obtained at 518°C.

time, s	Pressure CH_3CHO, mmHg
0	364
42	330
105	290
720	132

Calculate the rate constant for the decomposition of acetaldehyde from the above data.

A) 2.2×10^{-3}/s
B) 0.70 mmHg/s
C) 2.2×10^{-3}/mmHg·s
D) 6.7×10^{-6}/mmHg·s
E) 5.2×10^{-5}/mmHg·s

14.5 Nitric oxide gas (NO) reacts with chlorine gas according to the equation

$NO + \frac{1}{2} Cl_2 \rightarrow NOCl$.

The following initial rates of reaction have been measured for the given reagent concentrations.

Expt. #	Rate (M/hr)	NO (M)	Cl_2 (M)
1	1.19	0.50	0.50
2	4.79	1.00	0.50
3	9.59	1.00	1.00

Which of the following is the rate law (rate equation) for this reaction?

A) Rate = k[NO]

B) Rate = $k[NO][Cl_2]^{1/2}$

C) Rate = $k[NO][Cl_2]$

D) Rate = $k[NO]^2[Cl_2]$

E) Rate = $k[NO]^2[Cl_2]^2$

14.6 A reaction has the following rate law:

Rate = $k[A][B]^2$

In experiment 1, the concentrations of A and B are both 0.10 mol L^{-1}; in experiment 2, the concentrations are both 0.30 mol L^{-1}. If the temperature stays constant, what is the value of the ratio, Rate(2)/Rate(1)?

A) 3.0 B) 6.0 C) 9.0 D) 18 E) 27

14.7 The activation energy for the following first-order reaction is 102 kJ/mol.

$N_2O_5(g) \rightarrow 2NO_2(g) + (1/2)O_2(g)$

The value of the rate constant (k) is $1.35 \times 10^{-4}\ s^{-1}$ at 35°C. What is the value of k at 0°C (R = 8.314 J/mol K)?

A) $8.2 \times 10^{-7}\ s^{-1}$

B) $1.9 \times 10^{-5}\ s^{-1}$

C) $4.2 \times 10^{-5}\ s^{-1}$

D) $2.2 \times 10^{-2}\ s^{-1}$

E) None of these

14.8 The elementary reaction $HBr(g) + Br(g) \rightarrow H(g) + Br_2(g)$ is endothermic.

a. Would you expect the rate constant for the back reaction to be smaller or larger than that for the forward reaction? Explain, briefly.

b. Draw a fully-labeled reaction energy diagram for this reaction, showing the locations of the reactants, products and transition state.

Answers:

15.1. Ans: D
15.2. Ans: A
15.3. Ans: C
15.4. Ans: D
15.5. Ans: B
15.6. Ans: E
15.7. Ans: A
15.8. Ans: C
15.9. Ans: B
15.10. Ans: C
15.11. Ans: B
15.12. Ans: E
15.13. Ans: B
15.14. Ans: C
15.15. Ans: E

14.1. Ans: A
14.2. Ans: C
14.3. Ans: C
14.4. Ans: D
14.5. Ans: D
14.6. Ans: E
14.7. Ans: A
14.8. On your own

15-1 SOLIDS + LIQUIDS CONCENTRATIONS ARE CONSTANT SO BECOME PART OF K ("D")

15-2 LEAVE OUT SOLIDS, CHOOSE ("A")

15-3 RAISE CONCENTRATIONS TO THE POWER OF STOICHIOMETRY ie $3Cl_2(g)$ is $[Cl_2]^3$
CHOOSE ("C")

15-4 HERE WE DOUBLED EVERYTHING SO $K_c' = K_c^2 = (4.4\times10^9)^2$ (FIRST REACTION)
DOUBLED RXN $= 1.9\times10^{19}$ ("D")

BECAUSE $\frac{[Cl_2]^2[COCl_2]^2}{[CCl_4]^2[O_2]}$ is $\left(\frac{[Cl_2][COCl_2]}{[CCl_4][O_2]^{1/2}}\right)^2 = (K_c)^2$

15-5 $2H_2O_2(g) \rightleftharpoons 2H_2O(g) + O_2(g)$ $K_c = \frac{[H_2O]^2[O_2]}{[H_2O_2]^2}$ CAREFUL! THESE ARE CONCENTRATIONS

$\frac{1.75\text{ mol}}{2.5\text{ L}}$ ← CALCULATE $[H_2O_2]$

$\frac{1.20\text{ mol}}{2.5\text{ L}} = 0.48\text{ M}$ @ EQUIL. for H_2O_2

	H_2O_2	H_2O	O_2
I	0.700M	Ø	Ø
C	-2x	+2x	+x
E	0.48M	+2x	+x

Find x $0.700 - 2x = 0.48$
$-2x = -0.22$
$x = 0.11$

$[H_2O(g)] = 2x = 0.22$
$[O_2(g)] = x = 0.11$

$K_c = \frac{(0.22)^2(0.11)}{(0.48)^2}$

$K_c = 2.31\times10^{-2}$ ("B")

15-6 $Q_c = \frac{[N_2O_4]}{[NO_2]^2} = \frac{(0.016)}{(0.016)^2} = 62.5$ ("E")

15-7 $CO_{(g)} + Br_{2(g)} \rightleftharpoons COBr_{2(g)}$ 1 L container so calculating initial Conc is easy

	CO	Br_2	$COBr_2$
I	0.500M	0.400M	0
C	−x	−x	+x
E	0.500−x	0.400−x	0.233

↑ note x = 0.233

0.500 − 0.233 = 0.267   0.400 − 0.233 = 0.167

$K_c = \frac{[COBr_2]}{[CO][Br_2]} = \frac{0.233}{(0.267)(0.167)} = 5.23$ "A"

15-8 $2A_{(g)} \rightleftharpoons B_{(g)} + C_{(g)}$ $K_c = \frac{[B][C]}{[A]^2} = 0.035$

20.0 L container

$\frac{8 \text{ mol B}}{20.0L} = 0.400M$

$\frac{12.00 \text{ mol C}}{20L} = 0.600M$

	A	B	C
I	0	0.400M	0.600M
C	+2x	−x	−x
	2x	0.4−x	0.6−x

PLUG INTO Kc expression

$0.035 = \frac{[B][C]}{[A]^2} = \frac{(0.4-x)(0.6-x)}{(2x)^2}$

Now make your quadratic: $4x^2 \cdot 0.035 = 0.24 - 1x + x^2$

$0.14x^2 = 0.24 - x + x^2$

$0 = 0.24 - x + 0.86x^2$

$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

x = ~~0.824~~ or 0.339

↑ Larger than starting [B] or [C]

$[A] = 2x = 2 \times 0.339$

$= 0.678$ "C"

15-9 $K_p = K_c(RT)^{\Delta n}$ $\quad 1N_2O_4 \rightleftharpoons 2NO_2$

$\Delta n = 2-1 = 1$

$K_p = K_c RT$ ("B")

15-10 $2NO_{(g)} + Cl_{2(g)} \rightleftharpoons 2NOCl_{(g)}$ $\quad \Delta n = 2-3 = -1$

$K_p = K_c(RT)^{-1}$ so $K_c = K_p RT = 6.5\times10^{-4} \times 0.08206 \times 308$

$= 1.6\times10^{-2}$ ("C")

15-11 $K_p = K_c(RT)^{\Delta n}$ $\quad \Delta n = 0$ for $N_2 + O_2 \rightleftharpoons 2NO$ $(2-2=0)$

so $K_p = K_c = 4.1\times10^{-4}$ ("B")

15-12 $C_s + CO_{2(g)} \rightleftharpoons 2CO_{(g)}$ $\quad K_p = \dfrac{(P_{CO})^2}{(P_{CO_2})} = 10.7$

$P_T = 1\,atm = P_{CO} + P_{CO_2}$ substitute

$P_{CO_2} = 1 - P_{CO}$

$\dfrac{(P_{CO})^2}{(1-P_{CO})} = 10.7$

$P_{CO}^2 = 10.7 - 10.7P_{CO}$

$P_{CO}^2 + 10.7P_{CO} - 10.7 = 0$

Quadratic for P_{CO} $\quad P_{CO} = 0.921$ or ~~-11.6~~

CHOOSE "E"

15-13 $2HI_{(g)} \rightleftharpoons H_{2(g)} + I_{2(g)}$ $\quad K_c = \dfrac{[H_2][I_2]}{[HI]^2} = 0.0156$ @ 400°C

from 0.550 mol in 2.0 L

	$2HI$	H_2	I_2
I	0.275 M	0	0
C	$-2x$	$+x$	$+x$
E	$0.275-2x$	x	x

$0.275 - 2(0.0275)$

$= 0.22\,M$ ("B")

$\sqrt{0.0156 = \dfrac{x \cdot x}{(0.275-2x)^2}} = \sqrt{\dfrac{x^2}{(0.275-2x)^2}}$

$0.125 = \dfrac{x}{0.275-2x}$ $\quad x = 0.0275$

15-14 To make more prds, Add reactants (Q becomes less than K)

Remove prds (Q becomes less than K)

Increase pressure, Rxn Responds by going to side w/ fewer moles

for endothermic Rxns, need to add heat to force Rxn towards prds

So choose "C"

15-15 A - increase Vol, Lower P Room for more molecules Rxn would go right

B - remove NO; Q less than K; goes right

C Remove Br_2 same as B

D Add NoBr Q less than K

Yes! → E Decrease Temp favors Reactants for endothermic Rxns

14-1 2nd order $\left(\frac{1}{[A]_t}\right)^{-1} = \left(kt + \frac{1}{[A]_0}\right)^{-1}$ $k = 0.014\,M^{-1}s^{-1}$

$t = 10800\,s$ (3hrs)

$[A]_0 = 0.025\,M$

$[A]_t = \left(0.014 \cdot 10800 + \frac{1}{0.025}\right)^{-1}$

$= (151.2 + 40)^{-1}$

$[A]_t = (191.2)^{-1} = \boxed{0.0052\,M}$ "B"

14-2 $\ln(k) = \ln(A e^{-E_a/RT})$

$\ln k = \frac{-E_a}{R} \times \frac{1}{T} + \ln A$

↑ slope "C"

14-3 Rate for F_2 use 1 & 3 Rate doubles w/ conc doubles

first order

or if you wish Rate $\propto [F_2]^x$

$2 = 2^x$

$\ln 2 = x \ln 2$

$1 = \frac{\ln 2}{\ln 2} = x$

for Cl_2O use 1 + 2

conc × 4 Rate × 4

first order again "C"

14-4 use $\frac{1}{[A]_t} = kt + \frac{1}{[A]_0}$ I used $t = 0$ & $t = 105$

$A = 364$ mmHg $A = 290$ mmHg

$\frac{1}{290} = k(105) + \frac{1}{364}$ (Just use 2 points)

$7.01 \times 10^{-4} = k(105)$

$6.68 \times 10^{-6} = k$ "D"

14-5 for NO use 1 + 2 conc doubles Rate × 4 Rate $\propto [\ ]^x$

2nd order $4 = 2^x$ $x = 2$

for Cl_2 2 & 3 conc doubles Rate doubles

first order "D"

14-6 $\frac{Rate(2)}{Rate(1)} = \frac{\cancel{k}(0.3)(0.3)^2}{\cancel{k}(0.1)(0.1)^2} = 27$ "E"

k's constant so cancels

14-7

$\ln \frac{k_1}{k_2} = \frac{E_a}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right)$

$\ln \frac{k_1}{1.35\times10^{-4}} = \frac{102000\ J/mol}{8.314\ J/mol\,K}\left(\frac{1}{308} - \frac{1}{273}\right)$

$k_2 = 1.35\times10^{-4}\ s^{-1}$ $T_2 = 308K$

$k_1 = ?$ $T_1 = 273K$

$e^{\ln\left(\frac{k_1}{1.35\times10^{-4}}\right)} = e^{(-5.10)}$

$\frac{k_1}{1.35\times10^{-4}} = 0.00606$

$k_1 = 8.17\times10^{-7}$ "A"

14-8