$AP^{®}$ Chemistry
2008 Free-Response Questions
Form B

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INFORMATION IN THE TABLE BELOW AND IN THE TABLES ON PAGES 3-5 MAY BE USEFUL IN ANSWERING THE QUESTIONS IN THIS SECTION OF THE EXAMINATION.

DO NOT DETACH FROM BOOK.

PERIODIC TABLE OF THE ELEMENTS

1 **H** 1.008																	2 **He** 4.00
3 **Li** 6.94	4 **Be** 9.01											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.30											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.90	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.1	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.75	52 **Te** 127.60	53 **I** 126.91	54 **Xe** 131.29
55 **Cs** 132.91	56 **Ba** 137.33	57 ***La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.85	75 **Re** 186.21	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
87 **Fr** (223)	88 **Ra** 226.02	89 **†Ac** 227.03	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (277)	109 **Mt** (268)	110 **Ds** (271)	111 **Rg** (272)							

*Lanthanide Series	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** (145)	62 **Sm** 150.4	63 **Eu** 151.97	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.04	71 **Lu** 174.97
†Actinide Series	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** (237)	94 **Pu** (244)	95 **Am** (243)	96 **Cm** (247)	97 **Bk** (247)	98 **Cf** (251)	99 **Es** (252)	100 **Fm** (257)	101 **Md** (258)	102 **No** (259)	103 **Lr** (262)

STANDARD REDUCTION POTENTIALS IN AQUEOUS SOLUTION AT 25°C

Half-reaction			$E°$(V)
$F_2(g) + 2e^-$	→	$2F^-$	2.87
$Co^{3+} + e^-$	→	Co^{2+}	1.82
$Au^{3+} + 3e^-$	→	$Au(s)$	1.50
$Cl_2(g) + 2e^-$	→	$2Cl^-$	1.36
$O_2(g) + 4H^+ + 4e^-$	→	$2H_2O(l)$	1.23
$Br_2(l) + 2e^-$	→	$2Br^-$	1.07
$2Hg^{2+} + 2e^-$	→	$Hg_2{}^{2+}$	0.92
$Hg^{2+} + 2e^-$	→	$Hg(l)$	0.85
$Ag^+ + e^-$	→	$Ag(s)$	0.80
$Hg_2{}^{2+} + 2e^-$	→	$2Hg(l)$	0.79
$Fe^{3+} + e^-$	→	Fe^{2+}	0.77
$I_2(s) + 2e^-$	→	$2I^-$	0.53
$Cu^+ + e^-$	→	$Cu(s)$	0.52
$Cu^{2+} + 2e^-$	→	$Cu(s)$	0.34
$Cu^{2+} + e^-$	→	Cu^+	0.15
$Sn^{4+} + 2e^-$	→	Sn^{2+}	0.15
$S(s) + 2H^+ + 2e^-$	→	$H_2S(g)$	0.14
$2H^+ + 2e^-$	→	$H_2(g)$	0.00
$Pb^{2+} + 2e^-$	→	$Pb(s)$	– 0.13
$Sn^{2+} + 2e^-$	→	$Sn(s)$	– 0.14
$Ni^{2+} + 2e^-$	→	$Ni(s)$	– 0.25
$Co^{2+} + 2e^-$	→	$Co(s)$	– 0.28
$Cd^{2+} + 2e^-$	→	$Cd(s)$	– 0.40
$Cr^{3+} + e^-$	→	Cr^{2+}	– 0.41
$Fe^{2+} + 2e^-$	→	$Fe(s)$	– 0.44
$Cr^{3+} + 3e^-$	→	$Cr(s)$	– 0.74
$Zn^{2+} + 2e^-$	→	$Zn(s)$	– 0.76
$2H_2O(l) + 2e^-$	→	$H_2(g) + 2OH^-$	– 0.83
$Mn^{2+} + 2e^-$	→	$Mn(s)$	– 1.18
$Al^{3+} + 3e^-$	→	$Al(s)$	– 1.66
$Be^{2+} + 2e^-$	→	$Be(s)$	– 1.70
$Mg^{2+} + 2e^-$	→	$Mg(s)$	– 2.37
$Na^+ + e^-$	→	$Na(s)$	– 2.71
$Ca^{2+} + 2e^-$	→	$Ca(s)$	– 2.87
$Sr^{2+} + 2e^-$	→	$Sr(s)$	– 2.89
$Ba^{2+} + 2e^-$	→	$Ba(s)$	– 2.90
$Rb^+ + e^-$	→	$Rb(s)$	– 2.92
$K^+ + e^-$	→	$K(s)$	– 2.92
$Cs^+ + e^-$	→	$Cs(s)$	– 2.92
$Li^+ + e^-$	→	$Li(s)$	– 3.05

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ATOMIC STRUCTURE

$$E = h\nu \qquad c = \lambda\nu$$

$$\lambda = \frac{h}{m\upsilon} \qquad p = m\upsilon$$

$$E_n = \frac{-2.178 \times 10^{-18}}{n^2} \text{ joule}$$

E = energy
ν = frequency
λ = wavelength
p = momentum
υ = velocity
n = principal quantum number
m = mass

Speed of light, $c = 3.0 \times 10^{8}$ m s^{-1}

Planck's constant, $h = 6.63 \times 10^{-34}$ J s

Boltzmann's constant, $k = 1.38 \times 10^{-23}$ J K^{-1}

Avogadro's number $= 6.022 \times 10^{23}$ mol^{-1}

Electron charge, $e = -1.602 \times 10^{-19}$ coulomb

1 electron volt per atom = 96.5 kJ mol^{-1}

EQUILIBRIUM

$$K_a = \frac{[H^+][A^-]}{[HA]}$$

$$K_b = \frac{[OH^-][HB^+]}{[B]}$$

$$K_w = [OH^-][H^+] = 1.0 \times 10^{-14} \text{ @ } 25°\text{C}$$
$$= K_a \times K_b$$

$$\text{pH} = -\log[H^+],\ \text{pOH} = -\log[OH^-]$$

$$14 = \text{pH} + \text{pOH}$$

$$\text{pH} = \text{p}K_a + \log\frac{[A^-]}{[HA]}$$

$$\text{pOH} = \text{p}K_b + \log\frac{[HB^+]}{[B]}$$

$$\text{p}K_a = -\log K_a,\ \text{p}K_b = -\log K_b$$

$$K_p = K_c(RT)^{\Delta n},$$

where Δn = moles product gas − moles reactant gas

Equilibrium Constants

K_a (weak acid)
K_b (weak base)
K_w (water)
K_p (gas pressure)
K_c (molar concentrations)

THERMOCHEMISTRY/KINETICS

$$\Delta S° = \sum S° \text{ products} - \sum S° \text{ reactants}$$

$$\Delta H° = \sum \Delta H_f° \text{ products} - \sum \Delta H_f° \text{ reactants}$$

$$\Delta G° = \sum \Delta G_f° \text{ products} - \sum \Delta G_f° \text{ reactants}$$

$$\Delta G° = \Delta H° - T\Delta S°$$
$$= -RT\ln K = -2.303\,RT\log K$$
$$= -n\mathcal{F}E°$$

$$\Delta G = \Delta G° + RT\ln Q = \Delta G° + 2.303\,RT\log Q$$

$$q = mc\Delta T$$

$$C_p = \frac{\Delta H}{\Delta T}$$

$$\ln[A]_t - \ln[A]_0 = -kt$$

$$\frac{1}{[A]_t} - \frac{1}{[A]_0} = kt$$

$$\ln k = \frac{-E_a}{R}\left(\frac{1}{T}\right) + \ln A$$

$S°$ = standard entropy
$H°$ = standard enthalpy
$G°$ = standard free energy
$E°$ = standard reduction potential
T = temperature
n = moles
m = mass
q = heat
c = specific heat capacity
C_p = molar heat capacity at constant pressure
E_a = activation energy
k = rate constant
A = frequency factor

Faraday's constant, $\mathcal{F}$ = 96,500 coulombs per mole of electrons

Gas constant, $R = 8.31$ J mol^{-1} K^{-1}
$= 0.0821$ L atm mol^{-1} K^{-1}
$= 62.4$ L torr mol^{-1} K^{-1}
$= 8.31$ volt coulomb mol^{-1} K^{-1}

GASES, LIQUIDS, AND SOLUTIONS

$$PV = nRT$$

$$\left(P + \frac{n^2 a}{V^2}\right)(V - nb) = nRT$$

$$P_A = P_{total} \times X_A, \text{where } X_A = \frac{\text{moles A}}{\text{total moles}}$$

$$P_{total} = P_A + P_B + P_C + ...$$

$$n = \frac{m}{\boldsymbol{M}}$$

$$\text{K} = {}^\circ\text{C} + 273$$

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

$$D = \frac{m}{V}$$

$$u_{rms} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3RT}{\boldsymbol{M}}}$$

$$KE \text{ per molecule} = \frac{1}{2}mv^2$$

$$KE \text{ per mole} = \frac{3}{2}RT$$

$$\frac{r_1}{r_2} = \sqrt{\frac{\boldsymbol{M}_2}{\boldsymbol{M}_1}}$$

molarity, M = moles solute per liter solution

molality = moles solute per kilogram solvent

$$\Delta T_f = iK_f \times \text{molality}$$

$$\Delta T_b = iK_b \times \text{molality}$$

$$\pi = iMRT$$

$$A = abc$$

OXIDATION-REDUCTION; ELECTROCHEMISTRY

$$Q = \frac{[\text{C}]^c\,[\text{D}]^d}{[\text{A}]^a\,[\text{B}]^b}, \text{ where } a\,\text{A} + b\,\text{B} \rightarrow c\,\text{C} + d\,\text{D}$$

$$I = \frac{q}{t}$$

$$E_{\text{cell}} = E^\circ_{\text{cell}} - \frac{RT}{n\mathcal{F}}\ln Q = E^\circ_{\text{cell}} - \frac{0.0592}{n}\log Q \quad @\ 25^\circ\text{C}$$

$$\log K = \frac{nE^\circ}{0.0592}$$

P = pressure
V = volume
T = temperature
n = number of moles
D = density
m = mass
v = velocity

u_{rms} = root-mean-square speed
KE = kinetic energy
r = rate of effusion
$\boldsymbol{M}$ = molar mass
π = osmotic pressure
i = van't Hoff factor
K_f = molal freezing-point depression constant
K_b = molal boiling-point elevation constant
A = absorbance
a = molar absorptivity
b = path length
c = concentration
Q = reaction quotient
I = current (amperes)
q = charge (coulombs)
t = time (seconds)
E° = standard reduction potential
K = equilibrium constant

Gas constant, R = 8.31 J mol^{-1} K^{-1}
= 0.0821 L atm mol^{-1} K^{-1}
= 62.4 L torr mol^{-1} K^{-1}
= 8.31 volt coulomb mol^{-1} K^{-1}

Boltzmann's constant, k = 1.38×10^{-23} J K^{-1}

K_f for H_2O = 1.86 K kg mol^{-1}

K_b for H_2O = 0.512 K kg mol^{-1}

1 atm = 760 mm Hg
= 760 torr

STP = 0.00 °C and 1.0 atm

Faraday's constant, $\mathcal{F}$ = 96,500 coulombs per mole of electrons

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CHEMISTRY

Section II

(Total time—95 minutes)

Part A

Time—55 minutes

YOU MAY USE YOUR CALCULATOR FOR PART A.

CLEARLY SHOW THE METHOD USED AND THE STEPS INVOLVED IN ARRIVING AT YOUR ANSWERS. It is to your advantage to do this, since you may obtain partial credit if you do and you will receive little or no credit if you do not. Attention should be paid to significant figures.

Be sure to write all your answers to the questions on the lined pages following each question in the goldenrod booklet. Do NOT write your answers on the lavender insert.

Answer Questions 1, 2, and 3. The Section II score weighting for each question is 20 percent.

1. Answer the following questions regarding the decomposition of arsenic pentafluoride, $AsF_5(g)$.

(a) A 55.8 g sample of $AsF_5(g)$ is introduced into an evacuated 10.5 L container at 105°C.

(i) What is the initial molar concentration of $AsF_5(g)$ in the container?

(ii) What is the initial pressure, in atmospheres, of the $AsF_5(g)$ in the container?

At 105°C, $AsF_5(g)$ decomposes into $AsF_3(g)$ and $F_2(g)$ according to the following chemical equation.

$$AsF_5(g) \rightleftarrows AsF_3(g) + F_2(g)$$

(b) In terms of molar concentrations, write the equilibrium-constant expression for the decomposition of $AsF_5(g)$.

(c) When equilibrium is established, 27.7 percent of the original number of moles of $AsF_5(g)$ has decomposed.

(i) Calculate the molar concentration of $AsF_5(g)$ at equilibrium.

(ii) Using molar concentrations, calculate the value of the equilibrium constant, K_{eq} , at 105°C.

(d) Calculate the mole fraction of $F_2(g)$ in the container at equilibrium.

GO ON TO THE NEXT PAGE.

$$A(g) + B(g) \rightarrow C(g) + D(g)$$

2. For the gas-phase reaction represented above, the following experimental data were obtained.

Experiment	Initial [A] (mol L^{-1})	Initial [B] (mol L^{-1})	Initial Reaction Rate (mol L^{-1} s^{-1})
1	0.033	0.034	6.67×10^{-4}
2	0.034	0.137	1.08×10^{-2}
3	0.136	0.136	1.07×10^{-2}
4	0.202	0.233	?

(a) Determine the order of the reaction with respect to reactant A . Justify your answer.

(b) Determine the order of the reaction with respect to reactant B . Justify your answer.

(c) Write the rate law for the overall reaction.

(d) Determine the value of the rate constant, k , for the reaction. Include units with your answer.

(e) Calculate the initial reaction rate for experiment 4.

(f) The following mechanism has been proposed for the reaction.

Step 1: $B + B \rightarrow E + D$ *slow*

Step 2: $E + A \rightleftarrows B + C$ *fast equilibrium*

Provide two reasons why the mechanism is acceptable.

(g) In the mechanism in part (f), is species E a catalyst, or is it an intermediate? Justify your answer.

3. A 0.150 g sample of solid lead(II) nitrate is added to 125 mL of 0.100 *M* sodium iodide solution. Assume no change in volume of the solution. The chemical reaction that takes place is represented by the following equation.

$$Pb(NO_3)_2(s) + 2\ NaI(aq) \rightarrow PbI_2(s) + 2\ NaNO_3(aq)$$

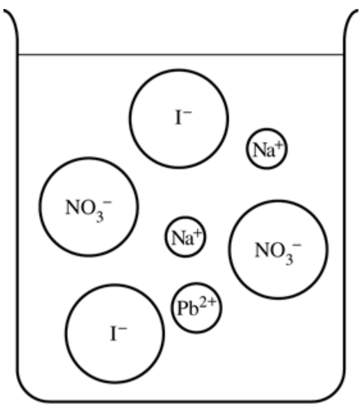
(a) List an appropriate observation that provides evidence of a chemical reaction between the two compounds.

(b) Calculate the number of moles of each reactant.

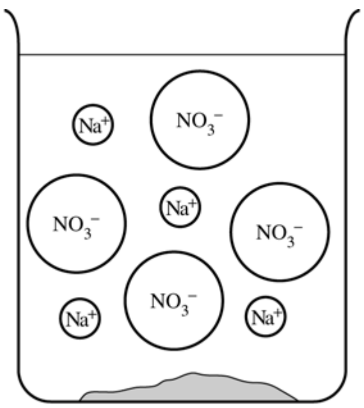
(c) Identify the limiting reactant. Show calculations to support your identification.

(d) Calculate the molar concentration of $NO_3^-(aq)$ in the mixture after the reaction is complete.

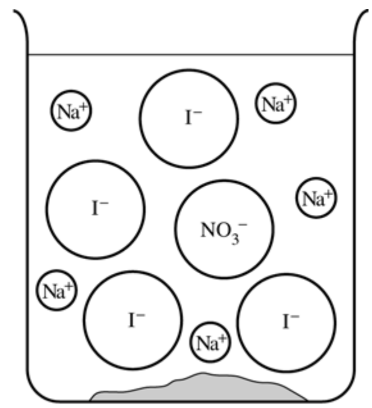
(e) Circle the diagram below that best represents the results after the mixture reacts as completely as possible. Explain the reasoning used in making your choice.



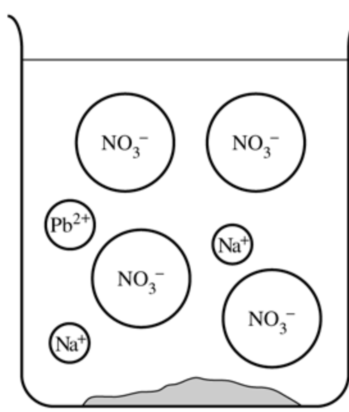
No Precipitate



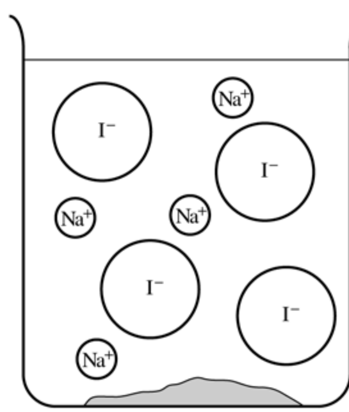
Solid PbI_2



Solid PbI_2



Solid PbI_2



Solid $Pb(NO_3)_2$

GO ON TO THE NEXT PAGE.

S T O P

If you finish before time is called, you may check your work on this part only.
Do not turn to the other part of the test until you are told to do so.

CHEMISTRY

Part B

Time—40 minutes

NO CALCULATORS MAY BE USED FOR PART B.

Answer Question 4 below. The Section II score weighting for this question is 10 percent.

4. For each of the following three reactions, in part (i) write a balanced equation for the reaction and in part (ii) answer the question about the reaction. In part (i), coefficients should be in terms of lowest whole numbers. Assume that solutions are aqueous unless otherwise indicated. Represent substances in solutions as ions if the substances are extensively ionized. Omit formulas for any ions or molecules that are unchanged by the reaction. You may use the empty space at the bottom of the next page for scratch work, but only equations that are written in the answer boxes provided will be graded.

EXAMPLE:

A strip of magnesium metal is added to a solution of silver(I) nitrate.

(i) Balanced equation:

$Mg + 2Ag^{+} \longrightarrow Mg^{2+} + 2Ag$

(ii) Which substance is oxidized in the reaction?

Mg is oxidized.

(a) Chlorine gas, an oxidizing agent, is bubbled into a solution of potassium bromide at 25°C.

(i) Balanced equation:

(ii) Predict the sign of $\Delta S°$ for the reaction at 25°C. Justify your prediction.

(b) Solid strontium hydroxide is added to a solution of nitric acid.

(i) Balanced equation:

(ii) How many moles of strontium hydroxide would react completely with 500. mL of 0.40 *M* nitric acid?

(c) A solution of barium chloride is added drop by drop to a solution of sodium carbonate, causing a precipitate to form.

(i) Balanced equation:

(ii) What happens to the pH of the sodium carbonate solution as the barium chloride is added to it?

Answer Question 5 and Question 6. The Section II score weighting for these questions is 15 percent each.

Your responses to these questions will be graded on the basis of the accuracy and relevance of the information cited. Explanations should be clear and well organized. Examples and equations may be included in your responses where appropriate. Specific answers are preferable to broad, diffuse responses.

5. The identity of an unknown solid is to be determined. The compound is one of the seven salts in the following table.

$Al(NO_3)_3 \cdot 9H_2O$	$BaCl_2 \cdot 2H_2O$	$CaCO_3$	$CuSO_4 \cdot 5H_2O$
$NaCl$	$BaSO_4$	$Ni(NO_3)_2 \cdot 6H_2O$	

Use the results of the following observations or laboratory tests to explain how each compound in the table may be eliminated or confirmed. The tests are done in sequence from (a) through (e).

(a) The unknown compound is white. In the table below, cross out the two compounds that can be eliminated using this observation. Be sure to cross out these same two compounds in the tables in parts (b), (c), and (d).

$Al(NO_3)_3 \cdot 9H_2O$	$BaCl_2 \cdot 2H_2O$	$CaCO_3$	$CuSO_4 \cdot 5H_2O$
$NaCl$	$BaSO_4$	$Ni(NO_3)_2 \cdot 6H_2O$	

(b) When the unknown compound is added to water, it dissolves readily. In the table below, cross out the two compounds that can be eliminated using this test. Be sure to cross out these same two compounds in the tables in parts (c) and (d).

$Al(NO_3)_3 \cdot 9H_2O$	$BaCl_2 \cdot 2H_2O$	$CaCO_3$	$CuSO_4 \cdot 5H_2O$
$NaCl$	$BaSO_4$	$Ni(NO_3)_2 \cdot 6H_2O$	

(c) When $AgNO_3(aq)$ is added to an aqueous solution of the unknown compound, a white precipitate forms. In the table below, cross out each compound that can be eliminated using this test. Be sure to cross out the same compound(s) in the table in part (d).

$Al(NO_3)_3 \cdot 9H_2O$	$BaCl_2 \cdot 2H_2O$	$CaCO_3$	$CuSO_4 \cdot 5H_2O$
$NaCl$	$BaSO_4$	$Ni(NO_3)_2 \cdot 6H_2O$	

(d) When the unknown compound is carefully heated, it loses mass. In the table below, cross out each compound that can be eliminated using this test.

$Al(NO_3)_3 \cdot 9H_2O$	$BaCl_2 \cdot 2H_2O$	$CaCO_3$	$CuSO_4 \cdot 5H_2O$
$NaCl$	$BaSO_4$	$Ni(NO_3)_2 \cdot 6H_2O$	

(e) Describe a test that can be used to confirm the identity of the unknown compound identified in part (d). Limit your confirmation test to a reaction between an aqueous solution of the unknown compound and an aqueous solution of one of the other soluble salts listed in the tables. Describe the expected results of the test; include the formula(s) of any product(s).

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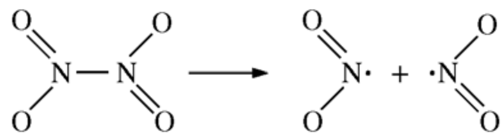
6. Use principles of thermodynamics to answer the following questions.

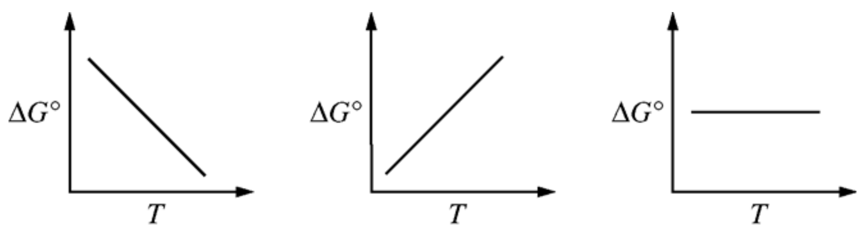
(a) The gas N_2O_4 decomposes to form the gas NO_2 according to the equation below.



(i) Predict the sign of $\Delta H°$ for the reaction. Justify your answer.

(ii) Predict the sign of $\Delta S°$ for the reaction. Justify your answer.

(b) One of the diagrams below best represents the relationship between $\Delta G°$ and temperature for the reaction given in part (a). Assume that $\Delta H°$ and $\Delta S°$ are independent of temperature.



Draw a circle around the correct graph. Explain why you chose that graph in terms of the relationship $\Delta G° = \Delta H° - T\Delta S°$.

(c) A reaction mixture of N_2O_4 and NO_2 is at equilibrium. Heat is added to the mixture while the mixture is maintained at constant pressure.

(i) Explain why the concentration of N_2O_4 decreases.

(ii) The value of K_{eq} at 25°C is 5.0×10^{-3}. Will the value of K_{eq} at 100°C be greater than, less than, or equal to this value?

(d) Using the value of K_{eq} at 25°C given in part (c)(ii), predict whether the value of $\Delta H°$ is expected to be greater than, less than, or equal to the value of $T\Delta S°$. Explain.

STOP

END OF EXAM