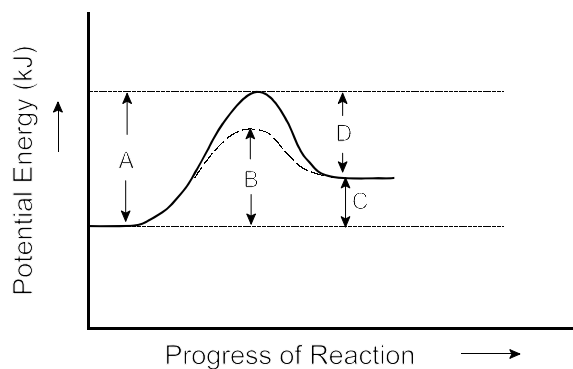# PART I
Total Value: 50%

Instructions: Shade the letter of the correct answer on the computer scorable answer sheet provided.

1.   In the potential energy diagram below, which represents the activation energy for the catalysed reaction?
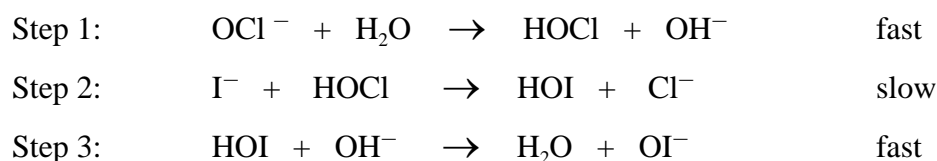

(A)   A
(B)   B
(C)   C
(D)   D

2.   In a reaction $E_{a \text{ (forward)}}$ is 28 kJ and $E_{a \text{ (reverse)}}$ is 54 kJ. Which describes the forward reaction?

	Reaction Type	ΔH (kJ)
(A)	endothermic	-26
(B)	endothermic	26
(C)	exothermic	-26
(D)	exothermic	26

3.   Marble chips and chalk dust are different forms of $CaCO_3(s)$. Which explains the difference in the reaction rate of each with vinegar?

(A)   concentration
(B)   pressure
(C)   surface area
(D)   temperature

4.   Which refers to each single step in a reaction mechanism?

(A)   activated complex
(B)   elementary
(C)   intermediate
(D)   rate determining

5. Which substance, when added to the reaction mechanism below, will have the greatest effect on the overall reaction rate?

Step 1: $OCl^- + H_2O \rightarrow HOCl + OH^-$ fast

Step 2: $I^- + HOCl \rightarrow HOI + Cl^-$ slow

Step 3: $HOI + OH^- \rightarrow H_2O + OI^-$ fast

(A) HOI
(B) H_2O
(C) I^-
(D) OCl^-

6. Which predicts how an equilibrium responds to imposed changes?

(A) Arrhenius definition
(B) Faraday's law
(C) Hess' law
(D) Le Châtelier's principle

7. Which change in the equilibrium below will result in the highest concentration of NO(g)?

$$N_2(g) + O_2(g) \rightleftharpoons 2 NO(g) \qquad \Delta H = + 182.6 \text{ kJ}$$
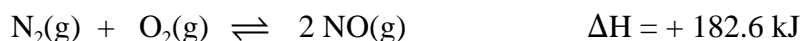
(A) adding a catalyst
(B) increasing pressure
(C) increasing temperature
(D) removing oxygen

8. The reaction below is allowed to reach equilibrium. If $O_2(g)$ is added to the system, what is the effect on the value of $[CO_2(g)]$ and the value of K?
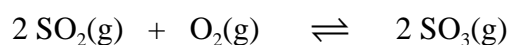
$$2 CO(g) + O_2(g) \rightleftharpoons 2 CO_2(g) + \text{heat}$$
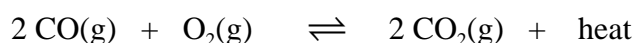
	$[CO_2(g)]$	K
(A)	decrease	constant
(B)	decrease	increase
(C)	increase	constant
(D)	increase	increase

9. When the reaction below is at equilibrium, $[Cl_2] = 4.4 \times 10^{-4}$ mol/L, $[N_2] = 1.4 \times 10^{-3}$ mol/L, and $[NCl_3] = 1.9 \times 10^{-1}$ mol/L. What is the value of K?

$$3 Cl_2(g) + N_2(g) \rightleftharpoons 2 NCl_3(g)$$
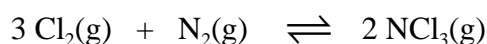
(A) 3.3×10^{-12}
(B) 3.2×10^{-6}
(C) 3.1×10^5
(D) 3.0×10^{11}

10. What is the equilibrium expression for the reaction below?

$$2\ SO_2(g)\ +\ O_2(g)\ \rightleftharpoons\ 2\ SO_3(g)$$

(A) $\dfrac{[SO_3]}{[SO_2][O_2]}$

(B) $\dfrac{[SO_3]^2}{[SO_2]^2[O_2]}$

(C) $\dfrac{[SO_2][O_2]}{[SO_3]}$

(D) $\dfrac{[SO_2]^2[O_2]}{[SO_3]^2}$

11. For the equilibrium below, the concentration of CO(g) and Cl_2(g) are both 0.200 mol/L. What is the equilibrium concentration of $COCl_2$?

$$CO(g)\ +\ Cl_2(g)\ \rightleftharpoons\ COCl_2(g)\qquad K = 21$$
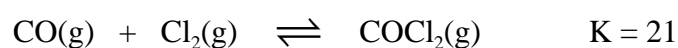
(A) 0.24
(B) 0.84
(C) 1.2
(D) 4.2

12. A sample of ammonia is placed in a sealed vessel and allowed to reach equilibrium. Using the graph below, what is the value of K?

$$2\ NH_3(g)\ \rightleftharpoons\ N_2(g)\ +\ 3\ H_2(g)$$
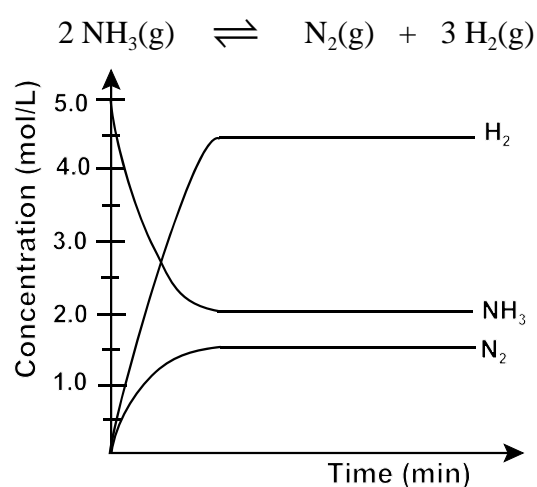
(A) 0.029
(B) 0.30
(C) 3.4
(D) 34

13. Which operationally defines an acidic acid solution?

(A) feels slippery
(B) pH is 8.0
(C) tastes bitter
(D) turns litmus red

14. Which is considered an Arrhenius base?

(A) CH_3OH
(B) CO_2
(C) HCN
(D) NaOH

15. According to Brⵁnsted-Lowry theory, what is an acid?

    (A)   electron acceptor
    (B)   electron donor
    (C)   proton acceptor
    (D)   proton donor

16. Which is a Brⵁnsted-Lowry conjugate acid-base pair for the reaction below?

$$HSO_3^-(aq) \ + \ NH_3(aq) \ \rightleftharpoons \ SO_3^{2-}(aq) \ + \ NH_4^+(aq)$$

    (A) $HSO_3^-(aq)$ and $NH_4^+(aq)$
    (B) $HSO_3^-(aq)$ and $SO_3^{2-}(aq)$
    (C) $SO_3^{2-}(aq)$ and $NH_3 (aq)$
    (D) $SO_3^{2-}(aq)$ and $NH_4^+(aq)$

17. Which 0.100 mol/L acid solution has the lowest pH?

    (A) $HNO_2(aq)$
    (B) $H_2CO_3(aq)$
    (C) $H_3BO_3(aq)$
    (D) $H_3PO_4(aq)$

18. Which represents the K_w expression for water?

    (A) $\left[H_3O^+ \right]\left[OH^- \right]$

    (B) $\dfrac{1}{\left[H_3O^+ \right]\left[OH^- \right]}$

    (C) $\dfrac{\left[H_3O^+ \right]\left[OH^- \right]}{\left[H_2O \right]}$

    (D) $\dfrac{\left[H_3O^+ \right]\left[OH^- \right]}{\left[H_2O \right]^2}$

19. What is the pOH for a 0.0150 mol/L hydrochloric acid solution?

    (A)   0.0150
    (B)   1.824
    (C)   12.176
    (D)   13.034

20. What is $[H_3O^+]$ of a 0.250 mol/L $Ba(OH)_2(aq)$ solution?

    (A) 2.00×10^{-14}
    (B) 4.00×10^{-14}
    (C)   0.125
    (D)   0.500

21. 100.0 mL of 0.625 mol/L HNO_3(aq) is diluted with deionized water to a final volume of 150.0 mL. What is the pH of the resulting solution?

(A) 0.204
(B) 0.380
(C) 13.398
(D) 13.620

22. What does the expression below represent?

$$\frac{\left[HCO_3^- \right]\left[OH^- \right]}{\left[CO_3^{2-} \right]}$$

(A) K_a for CO_3^{2-}
(B) K_a for HCO_3^-
(C) K_b for CO_3^{2-}
(D) K_b for HCO_3^-

23. What is the pH of the equivalence point when NaOH(aq) is titrated with HCl(aq)?

(A) 1
(B) 7
(C) 10
(D) 14

24. During a titration experiment to determine the concentration of acetic acid, a student pipettes a sample of the acid into a flask contaminated with a weak base. What effect will this have on the experiment?

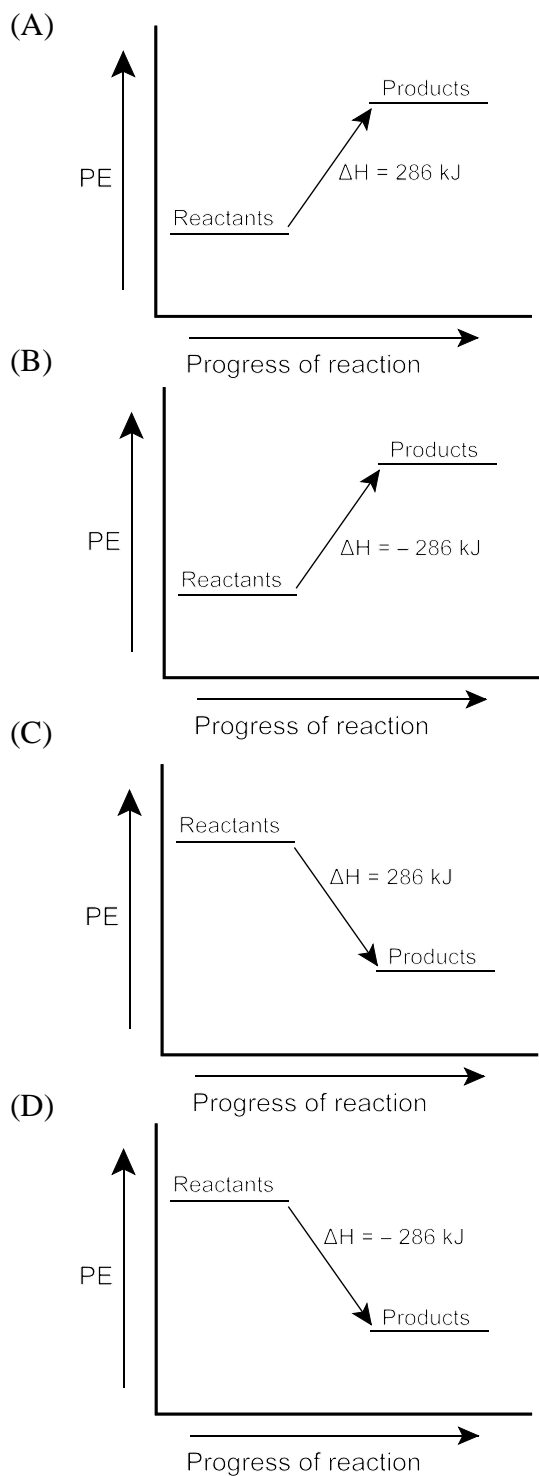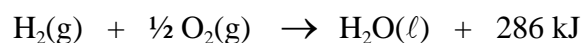|	Amount of titrant required	Calculated concentration
(A)	less	higher
(B)	less	lower
(C)	more	higher
(D)	more	lower

25. Which is the best definition for an acid-base indicator?

(A) strong acid
(B) strong base
(C) weak acid
(D) weak base

26. What is the pH range of a solution if orange IV indicator is yellow and methyl red indicator is red?

(A) 1.4 to 4.8
(B) 1.4 to 6.0
(C) 2.8 to 4.8
(D) 2.8 to 6.0

27. The titration curve below is for a 0.100 mol/L unknown acid titrated with sodium hydroxide. What is the unknown acid?

Volume of titrant (mL)
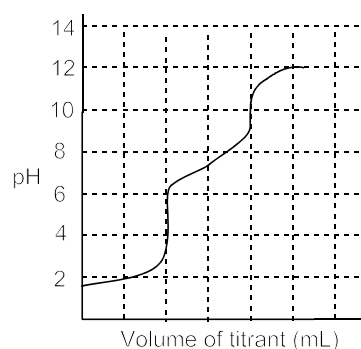
(A) HCl(aq)
(B) HCN(aq)
(C) H_2SO_3(aq)
(D) H_2SO_4(aq)

28. An unknown monoprotic acid with $K_a = 3.2 \times 10^9$ is titrated with an unknown weak base. Which is the best indicator to determine the equivalence point?

(A) indigo carmine
(B) methyl red
(C) orange IV
(D) phenolphthalein

29. What is the amount of heat released when the temperature of a 5.20 g iron nail changes from 22.0 °C to 38.5 °C? ($c_{iron} = 0.444$ J/g·°C)

(A) 22.1 J
(B) 38.1 J
(C) 50.8 J
(D) 88.9 J

30. The specific heat capacity of aluminum metal is 0.890 J/g·°C. What is the heat capacity of a 500.0 g aluminum frying pan?

(A) 0.00178 J/°C
(B) 0.890 J/°C
(C) 445 J/°C
(D) 562 J/°C

31. Which device best measures changes in kinetic energy?

(A) beaker
(B) calorimeter
(C) thermometer
(D) voltmeter

32. What happens to the water in a bomb calorimeter when an exothermic reaction occurs?

	Heat	Temperature
(A)	absorbs	decreases
(B)	absorbs	increases
(C)	releases	decreases
(D)	releases	increases

33. Which enthalpy diagram and ΔH best represent the reaction below?

$$H_2(g) \ + \ \tfrac{1}{2}\,O_2(g) \ \rightarrow \ H_2O(\ell) \ + \ 286\ kJ$$

(A)

PE — Products — ΔH = 286 kJ — Reactants — Progress of reaction

(B)

PE — Products — ΔH = − 286 kJ — Reactants — Progress of reaction

(C)

PE — Reactants — ΔH = 286 kJ — Products — Progress of reaction

(D)

PE — Reactants — ΔH = − 286 kJ — Products — Progress of reaction

34. When 1 mol of $CH_3OH(\ell)$ decomposes 129 kJ of heat is absorbed. Which thermochemical equation represents the decomposition of 2 mol of $CH_3OH(\ell)$?

(A) $2\,CH_3OH(\ell) \ + \ 129\ kJ \ \rightarrow \ 2\,CO(g) \ + \ 4\,H_2(g)$

(B) $2\,CH_3OH(\ell) \ + \ 258\ kJ \ \rightarrow \ 2\,CO(g) \ + \ 4\,H_2(g)$

(C) $2\,CH_3OH(\ell) \ \rightarrow \ 2\,CO(g) \ + \ 4\,H_2(g) \ + \ 129\ kJ$

(D) $2\,CH_3OH(\ell) \ \rightarrow \ 2\,CO(g) \ + \ 4\,H_2(g) \ + \ 258\ kJ$

35. If 5.74 kJ of energy is required to melt 50.0 g of sodium metal at its melting point, what is the molar heat of fusion for sodium metal?

(A) 0.378 kJ/mol
(B) 2.64 kJ/mol
(C) 12.5 kJ/mol
(D) 287 kJ/mol

36. The equation below shows the enthalpy change that occurs when NH_4NO_3 dissolves in water. Which describes this process?

$$NH_4NO_3(s) \; + \; 25.7 \text{ kJ} \; \rightarrow \; NH_4NO_3(aq)$$
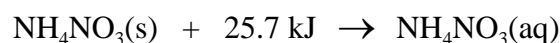
	ΔH (kJ/mol)	Water temperature
(A)	−25.7	decreases
(B)	−25.7	increases
(C)	25.7	decreases
(D)	25.7	increases

37. Which describes the energy changes that take place when a solid changes to a liquid at a constant temperature?

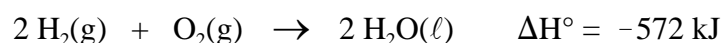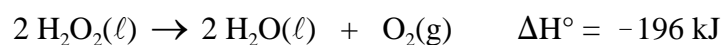|	Potential energy	Kinetic energy
(A)	constant	decreases
(B)	constant	increases
(C)	decreases	constant
(D)	increases	constant

38. Which involves the greatest amount of energy?

(A) combustion
(B) condensation
(C) neutralization
(D) nuclear fission

39. Which compound is most chemically stable?

	Species	ΔH°$_{formation}$ (kJ/mol)
(A)	$CCl_4(g)$	−95.7
(B)	$CS_2(g)$	116.7
(C)	$NH_3(g)$	−45.9
(D)	$N_2O(g)$	81.6

40.   Using the equations below, what is the enthalpy of formation of $H_2O_2(\ell)$?

$$2\ H_2O_2(\ell) \rightarrow 2\ H_2O(\ell)\ +\ O_2(g) \qquad \Delta H° = -196\ kJ$$

$$2\ H_2(g)\ +\ O_2(g)\ \rightarrow\ 2\ H_2O(\ell) \qquad \Delta H° = -572\ kJ$$
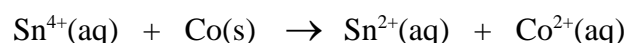
(A) -376 kJ/mol
(B) -188 kJ/mol
(C)   188 kJ/mol
(D)   376 kJ/mol

41.   Which describes reduction?

(A)   gain of electrons
(B)   gain of protons
(C)   loss of electrons
(D)   loss of protons

42.   Which is the oxidizing agent in the reaction below?

$$4\ Fe(s)\ +\ 3\ O_2(g)\ +\ 6\ H_2O(\ell)\ \rightarrow\ 4\ Fe(OH)_3(s)\ +\ energy$$
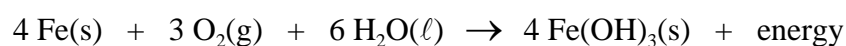
(A) $Fe(s)$
(B) $Fe(OH)_3(s)$
(C) $H_2O(\ell)$
(D) $O_2(g)$

43.   Which species is oxidized in the reaction below?

$$Sn^{4+}(aq)\ +\ Co(s)\ \rightarrow\ Sn^{2+}(aq)\ +\ Co^{2+}(aq)$$

(A) $Co(s)$
(B) $Co^{2+}(aq)$
(C) $Sn^{2+}(aq)$
(D) $Sn^{4+}(aq)$

44.   Which is an oxidation-reduction reaction?

(A) $HCO_3^-(aq)\ +\ H_3O^+(aq)\ \rightarrow\ 2\ H_2O(\ell)\ +\ CO_2(g)$
(B) $H_2SO_4(aq)\ \rightarrow\ H_2O(\ell)\ +\ SO_3(g)$
(C) $Pb^{2+}(aq)\ +\ 2\ I^-(aq)\ \rightarrow\ PbI_2(s)$
(D) $Zn(s)\ +\ 2\ CH_3COOH(aq)\ \rightarrow\ Zn^{2+}(aq)\ +\ 2\ CH_3COO^-(aq)\ +\ H_2(g)$

45.   In the electrochemical cell reaction below, what is the half-cell reaction that occurs at the anode?

$$3\ Zn^{2+}(aq)\ +\ 2\ Al(s)\ \rightarrow\ 3\ Zn(s)\ +\ 2\ Al^{3+}(aq)$$
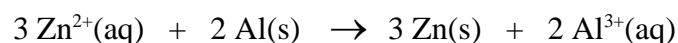
(A) $Al(s)\ \rightarrow\ Al^{3+}(aq)\ +\ 3\ e^-$
(B) $Al^{3+}(aq)\ +\ 3\ e^-\ \rightarrow\ Al(s)$
(C) $Zn(s)\ \rightarrow\ Zn^{2+}(aq)\ +\ 2\ e^-$
(D) $Zn^{2+}(aq)\ +\ 2\ e^-\ \rightarrow\ Zn(s)$

46. Which is the oxidation number of C in Na_2CO_3?

    (A)   0
    (B)   +2
    (C)   +4
    (D)   +6

47. Where does oxidation occur in an electrochemical cell?

    (A)   anode
    (B)   cathode
    (C)   external circuit
    (D)   salt bridge

48. Which best describes a spontaneous oxidation-reduction reaction?

    (A)   negative cell potential
    (B)   positive cell potential
    (C)   negative ΔH
    (D)   positive ΔH

49. Which describes a primary battery?

    (A)   electrolytic
    (B)   non-rechargeable
    (C)   non-spontaneous
    (D)   rechargeable

50. What voltage must be applied to decrease the mass of Ag(s) in the electrolytic cell reaction below?

$$2\,Ag^+(aq)\ +\ Cd(s) \rightarrow 2\,Ag(s)\ +\ Cd^{2+}(aq)$$

    (A)   0.40 V
    (B)   0.80 V
    (C)   1.20 V
   (D)   1.30 V

PART II
Total Value: 50%

Instructions: Complete all items in this section. Your responses should be clearly presented in a well-organized manner with proper use of units, formulae and significant figures where appropriate.

Value

4% 51.(a) In a lab, data from two trials of the reaction below were collected. Graph A illustrates the volume of oxygen produced over time for each trial.
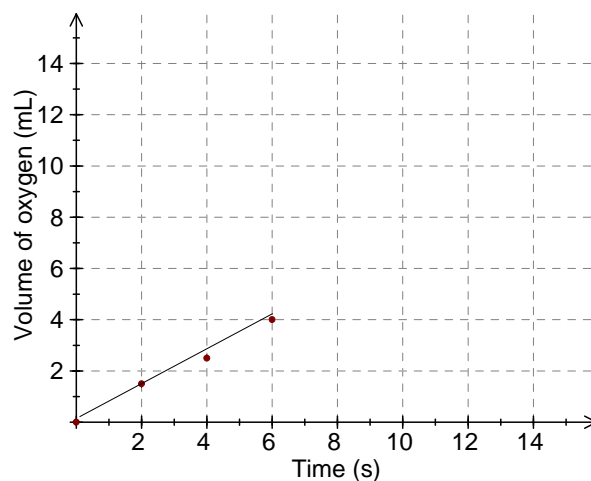
$$2\,H_2O_2(aq) \rightarrow 2\,H_2O(\ell) + O_2(g)$$
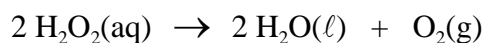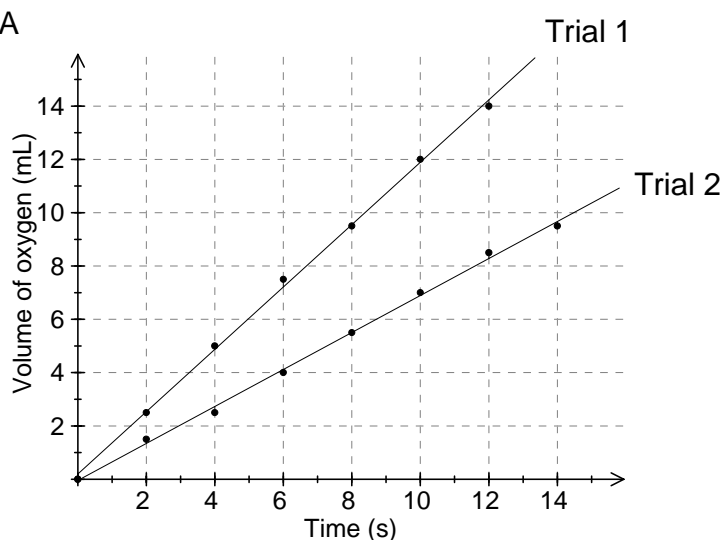
Graph A

i) Which trial has the highest rate of O_2 production?

_____

_____

ii) On Graph B below, show how trial 2 will change if a catalyst is added after 6 seconds.

Graph B

iii) Explain how one factor, other than a catalyst, could cause the different rates for trials 1 and 2 shown in Graph A.

_____

_____

_____

_____

_____

_____

51.(b) The mechanism below shows the decomposition of ozone in the upper atmosphere.

Step	Reaction Mechanism
1	$O_3(g) \rightarrow O_2(g) + O(g)$
2	$O_3(g) + NO(g) \rightarrow NO_2(g) + O_2(g)$
3	$NO_2(g) + O(g) \rightarrow NO(g) + O_2(g)$

i)   What is the equation for the overall reaction?

ii)   Identify reaction intermediate(s) and/or catalyst(s) present.

Reaction Intermediate(s):

Catalyst(s):

iii) Step 1 of the reaction mechanism does not occur unless ultraviolet radiation is present. Describe the role that ultraviolet radiation plays in the reaction.

_____

_____

_____

_____

3%   (c)   0.500 mol of $H_2O_2(g)$ are placed in a 2.00 L flask at a certain temperature and allowed to establish the equilibrium below. If there are 0.150 mol of $O_2(g)$ in the flask at equilibrium, calculate K for the reaction.

$$2\,H_2O_2(g) \rightleftharpoons 2\,H_2O(g) + O_2(g)$$
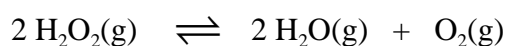
2%   51.(d) At 25 °C the value of K is 1.6×10^{-21}, while at 827 °C the value of K is 10.0. Explain whether the reaction is endothermic or exothermic.

$$C(s) \;+\; H_2O(g) \quad \rightleftharpoons \quad CO(g) \;+\; H_2(g)$$

_____

_____

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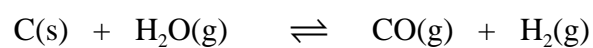
2%   52.(a) Determine the Brønsted-Lowry acid-base neutralization reaction that occurs between $NaHCO_3(aq)$ and $NH_4NO_2(aq)$.

4%   (b)   Calculate the pH of a 0.297 mol/L solution of hypochlorous acid, $HOCl(aq)$, which has $K_a = 2.9 \times 10^{-8}$.
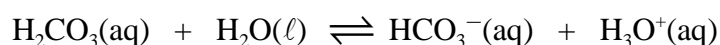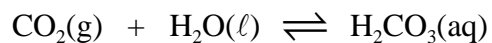
2%   52.(c) Using the data below, determine which solution is the best conductor of electricity, and explain why.

	Solution A	Solution B	Solution C
Name	HCl(aq)	$CH_3COOH(aq)$	LiOH(aq)
Volume (mL)	45	35	35
Moles of Solute	1.10×10^{-3}	1.50×10^{-2}	1.50×10^{-2}

4%   (d) Calculate the concentration and pH of a solution formed by mixing 25.00 mL of 0.125 mol/L HBr(aq), with 70.00 mL of 0.242 mol/L LiOH(aq).

2%   52.(e) A person's breathing rate is slowed as a result of a stroke. With reference to the equations below, explain if the person is at risk for acidosis or alkalosis.
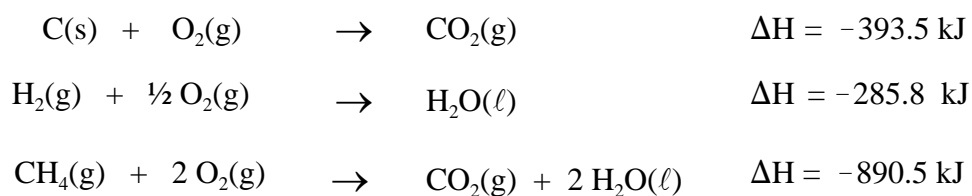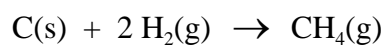
$$CO_2(g) \; + \; H_2O(\ell) \; \rightleftharpoons \; H_2CO_3(aq)$$

$$H_2CO_3(aq) \; + \; H_2O(\ell) \; \rightleftharpoons \; HCO_3{}^-(aq) \; + \; H_3O^+(aq)$$

_____

_____

_____

_____

_____

_____

_____

_____

5%   53.(a) 1125.4 g of water at 10.36 °C is cooled to 0 °C and frozen.

i)   Calculate how much heat is released in this process.

ii)   Calculate the number of moles of ammonia that can undergo a phase change from liquid to gas, using the energy from the process above.
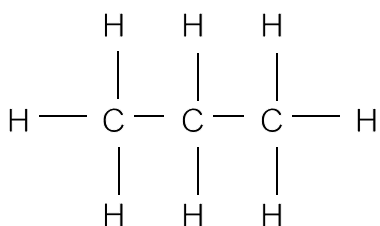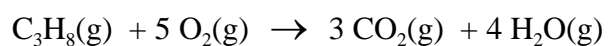
$$NH_3(\ell) \; \rightarrow \; NH_3(g) \qquad \Delta H^\circ{}_{vap} = +23.3 \text{ kJ/mol}$$

4%   53.(b) Using the data determine ΔH for the reaction below.

$$C(s) + 2 H_2(g) \rightarrow CH_4(g)$$

$C(s) + O_2(g)$	$\rightarrow$	$CO_2(g)$	$\Delta H = -393.5$ kJ
$H_2(g) + \frac{1}{2} O_2(g)$	$\rightarrow$	$H_2O(\ell)$	$\Delta H = -285.8$ kJ
$CH_4(g) + 2 O_2(g)$	$\rightarrow$	$CO_2(g) + 2 H_2O(\ell)$	$\Delta H = -890.5$ kJ

4%   (c)   Use the data below to calculate the fuel value of propane.

$$C_3H_8(g) + 5 O_2(g) \rightarrow 3 CO_2(g) + 4 H_2O(g)$$

Bond	Bond Energy (kJ/mol)
C – H	338
C – C	347
O = O	498
C = O	745
H – O	460

3%   54.(a) Balance the redox reaction below under acidic conditions.

$$H_2S \ + \ Cr_2O_7^{2-} \ \rightarrow \ Cr^{3+} \ + \ S$$
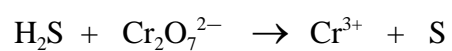
4%   (b)   Calculate how many minutes it would take to produce 5.40 g of aluminum from molten bauxite, Al_2O_3, using a current of 5.00 A.

Value

3%   54.(c) In the diagram below, identify the reaction that is taking place in the beaker on the right and identify electrode X. Explain your choice.

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