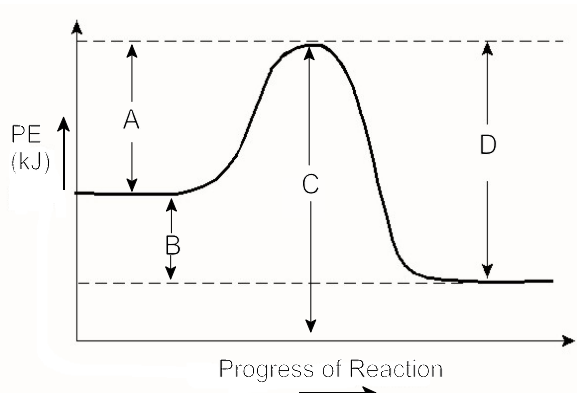


**PART I**  
**Total Value: 50%**

**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 reverse reaction?



- (A) A  
(B) B  
(C) C  
(D) D
2. Which is true about an activated complex?

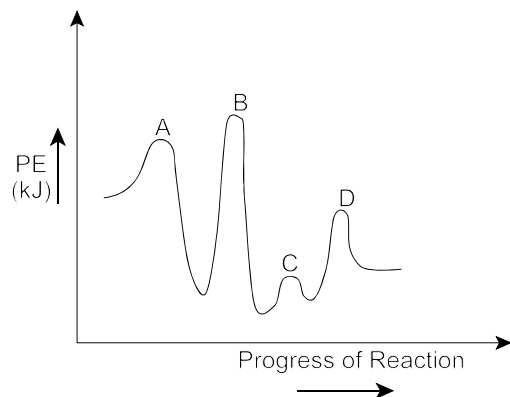
	Stability	Potential Energy
(A)	stable	high
(B)	stable	low
(C)	unstable	high
(D)	unstable	low

3. When studying the effect of temperature on the rate of the reaction below, what must be kept constant?

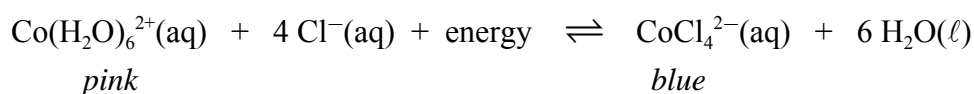


- (A) concentration of HCl(aq)  
(B) concentration of NaCl(aq)  
(C) pressure of reaction vessel  
(D) volume of reaction vessel
4. What is produced in one step of a reaction mechanism and consumed in a later step?
- (A) activated complex  
(B) catalyst  
(C) inhibitor  
(D) intermediate
5. Which must occur for a chemical reaction to take place?
- (A) addition of a catalyst  
(B) addition of energy  
(C) collisions between reacting particles  
(D) formation of a reaction intermediate

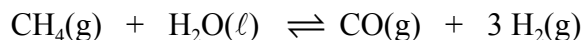
6. In the graph below, what is the rate determining step?



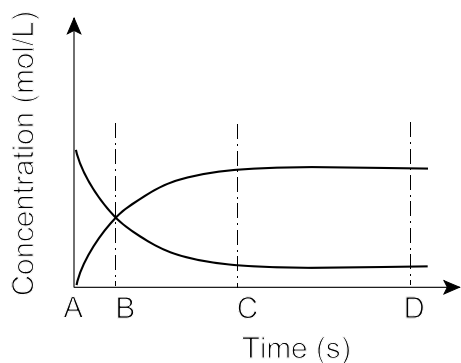
- (A) A  
 (B) B  
 (C) C  
 (D) D
7. What is true for the equilibrium below?



- (A) Cooling the reaction flask will make the colour turn blue.  
 (B) Cooling the reaction flask will make the colour turn pink.  
 (C) Decreasing pressure will make the colour turn blue.  
 (D) Decreasing pressure will make the colour turn pink.
8. At equilibrium, 2.2 mol of  $\text{CH}_4(\text{g})$ , 2.2 mol of  $\text{H}_2\text{O}(\ell)$ , 0.12 mol of  $\text{CO}(\text{g})$  and 0.36 mol of  $\text{H}_2(\text{g})$  are present in a 1.0 L container. What is the value of  $K_{\text{eq}}$  for the equilibrium below?

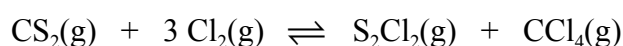


- (A)  $1.2 \times 10^{-3}$   
 (B)  $2.5 \times 10^{-3}$   
 (C)  $3.9 \times 10^2$   
 (D)  $8.6 \times 10^2$
9. The graph below refers to an equilibrium. When does the system reach equilibrium?

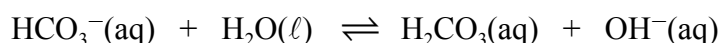


- (A) A  
 (B) B  
 (C) C  
 (D) D

10. Why is a chemical equilibrium described as dynamic?
- (A) Concentration of chemical species remains constant.
  - (B) Minimum energy is achieved.
  - (C) Reactants and products continue to form.
  - (D) Temperature remains constant.
11. In the equilibrium system below, which change would decrease the concentration of  $O_2(g)$ ?
- $$N_2(g) + 2 O_2(g) + \text{energy} \rightleftharpoons N_2O_4(g)$$
- (A) decrease the concentration of  $N_2(g)$
  - (B) decrease the pressure of the reaction vessel
  - (C) increase the temperature
  - (D) increase the volume of the reaction vessel
12. In a 1.0 L container, 2.0 moles of  $CS_2(g)$  and 4.0 moles of  $Cl_2(g)$  are mixed to establish the equilibrium below. If 0.30 moles of  $CCl_4(g)$  are present at equilibrium, how much  $Cl_2(g)$  remains?



- (A) 0.30 mol
  - (B) 0.90 mol
  - (C) 3.1 mol
  - (D) 3.9 mol
13. Which is true of acids?
- (A) feel slippery
  - (B) have a bitter taste
  - (C) react with metals to produce  $H_2(g)$
  - (D) turn red litmus paper blue
14. Which defines a modern Arrhenius acid?
- (A) ionizes in water to produce  $H^+$
  - (B) ionizes in water to produce  $OH^-$
  - (C) reacts with water to produce  $H_3O^+$
  - (D) reacts with water to produce  $OH^-$
15. In the reaction below,  $HCO_3^-(aq)$  is behaving as which type of substance?



- (A) Arrhenius acid
- (B) Arrhenius base
- (C) Brønsted-Lowry acid
- (D) Brønsted-Lowry base

16. Which is the conjugate acid and conjugate base of  $\text{HPO}_4^{2-}$ ?

	Conjugate Acid	Conjugate Base
(A)	$\text{H}_2\text{PO}_4^-$	$\text{H}_3\text{PO}_4$
(B)	$\text{H}_2\text{PO}_4^-$	$\text{PO}_4^{3-}$
(C)	$\text{H}_3\text{PO}_4$	$\text{PO}_4^{3-}$
(D)	$\text{PO}_4^{3-}$	$\text{H}_2\text{PO}_4^-$

17. Which 0.10 mol/L solution has the lowest  $[\text{OH}^-]$ ?

- (A)  $\text{F}^-(\text{aq})$
- (B)  $\text{HCO}_3^-(\text{aq})$
- (C)  $\text{SO}_3^{2-}(\text{aq})$
- (D)  $\text{SO}_4^{2-}(\text{aq})$

18. Which describes the relationship between acid strength and  $K_a$  value?

	Acid Strength	$K_a$ Value
(A)	decreases	decreases
(B)	decreases	remains constant
(C)	increases	decreases
(D)	increases	remains constant

19. Which best represents the Brønsted-Lowry reaction between  $\text{NaOH}(\text{aq})$  and  $\text{HF}(\text{aq})$ ?

- (A)  $\text{OH}^-(\text{aq}) + \text{H}^+(\text{aq}) \rightarrow \text{H}_2\text{O}(\ell)$
- (B)  $\text{OH}^-(\text{aq}) + \text{HF}(\text{aq}) \rightarrow \text{H}_2\text{O}(\ell) + \text{F}^-(\text{aq})$
- (C)  $\text{Na}^+(\text{aq}) + \text{OH}^-(\text{aq}) + \text{H}^+(\text{aq}) + \text{F}^-(\text{aq}) \rightarrow \text{H}_2\text{O}(\ell) + \text{Na}^+(\text{aq}) + \text{F}^-(\text{aq})$
- (D)  $\text{NaOH}(\text{aq}) + \text{F}^-(\text{aq}) \rightarrow \text{OH}^-(\text{aq}) + \text{NaF}(\text{aq})$

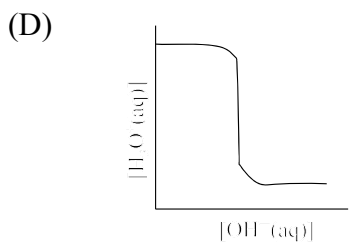
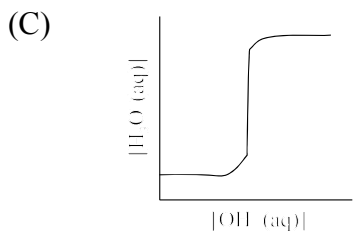
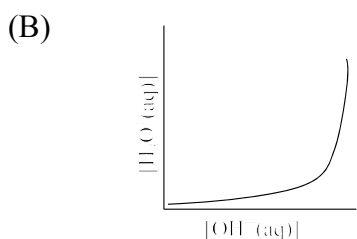
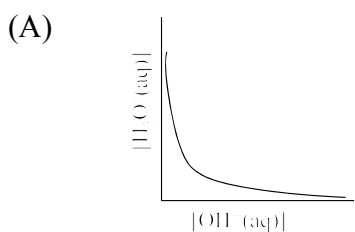
20. What is the  $K_w$  expression for the ionization of water?

- (A)  $K_w = \frac{[\text{OH}^-][\text{H}_3\text{O}^+]}{[\text{H}_2\text{O}]^2}$
- (B)  $K_w = \frac{[\text{H}_2\text{O}]^2}{[\text{OH}^-][\text{H}_3\text{O}^+]}$
- (C)  $K_w = \frac{1}{[\text{OH}^-][\text{H}_3\text{O}^+]}$
- (D)  $K_w = [\text{OH}^-][\text{H}_3\text{O}^+]$

21. What must occur to  $[\text{H}_3\text{O}^+]$  in order to change the pH of a solution from 2.0 to 4.0?

- (A) decrease by a factor of 2
- (B) decrease by a factor of 100
- (C) increase by a factor of 2
- (D) increase by a factor of 100

22. What is the pH of a solution with  $[\text{H}_3\text{O}^+(\text{aq})] = 2.3 \times 10^{-10} \text{ mol/L}$ ?
- (A) 4.36  
 (B) 7.00  
 (C) 9.64  
 (D) 10.23
23. In the titration of an acid with a base, what substance is used for the final rinse of the pipette?
- (A) acid  
 (B) base  
 (C) deionized water  
 (D) soap
24. Which graph illustrates the relationship between  $[\text{H}_3\text{O}^+(\text{aq})]$  and  $[\text{OH}^-(\text{aq})]$  in a solution?



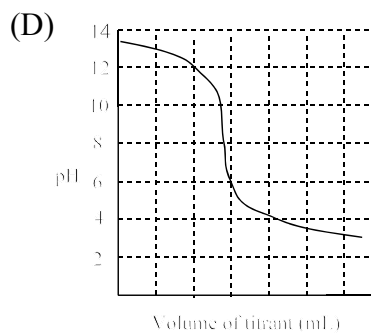
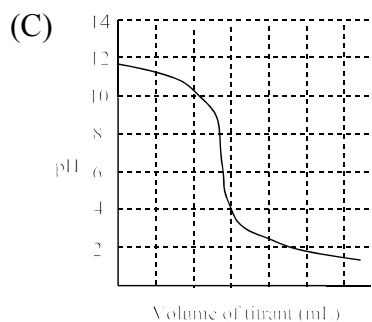
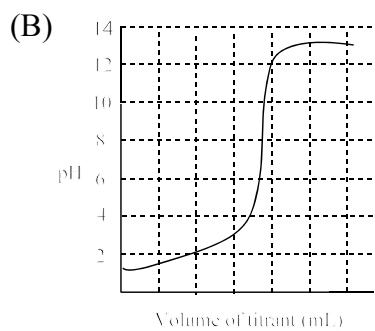
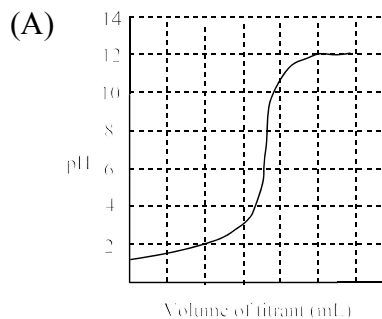
25. Which substance is dibasic?
- (A)  $\text{HPO}_4^{2-}$   
 (B)  $\text{H}_2\text{PO}_4^-$   
 (C)  $\text{HSO}_4^-$   
 (D)  $\text{H}_2\text{SO}_4$

26. What does the expression below represent?

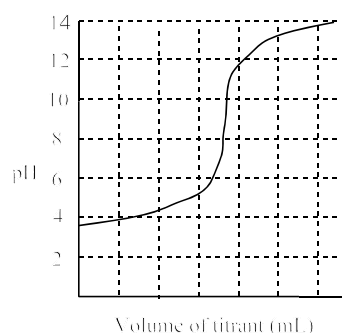
$$\frac{[\text{H}_2\text{P}_2\text{O}_7^{2-}][\text{H}_3\text{O}^+]}{[\text{H}_3\text{P}_2\text{O}_7^-]}$$

- (A)  $K_a$  for  $\text{H}_2\text{P}_2\text{O}_7^{2-}$   
 (B)  $K_a$  for  $\text{H}_3\text{P}_2\text{O}_7^-$   
 (C)  $K_b$  for  $\text{H}_2\text{P}_2\text{O}_7^{2-}$   
 (D)  $K_b$  for  $\text{H}_3\text{P}_2\text{O}_7^-$

27. A 0.50 mol/L solution of an unknown acid has a pH of 1.4. Which graph shows the titration of this acid with 0.10 mol/L sodium hydroxide, NaOH?



28. Which indicator is best for the titration shown in the curve below?



- (A) methyl orange  
 (B) orange IV  
 (C) thymol blue  
 (D) 1,3,5 - trinitrobenzene
29. Which piece of equipment should be used to create an isolated system?
- (A) aluminum can  
 (B) bomb calorimeter  
 (C) stoppered flask  
 (D) test tube
30. For a given substance, which process involves the largest heat change?
- (A) (g)  $\rightarrow$  (l)  
 (B) (g)  $\rightarrow$  (s)  
 (C) (l)  $\rightarrow$  (g)  
 (D) (l)  $\rightarrow$  (s)
31. Which compound is most stable?
- (A)  $\text{CS}_2(\text{g}), \Delta H_f^\circ = 117 \text{ kJ/mol}$   
 (B)  $\text{C}_2\text{H}_4(\text{g}), \Delta H_f^\circ = 52.4 \text{ kJ/mol}$   
 (C)  $\text{C}_2\text{H}_6(\text{g}), \Delta H_f^\circ = -84.0 \text{ kJ/mol}$   
 (D)  $\text{CO}_2(\text{g}), \Delta H_f^\circ = -394 \text{ kJ/mol}$
32. A bathtub and a teacup are both full of water at  $20.0^\circ\text{C}$ . Which best illustrates the relationship between the heat capacity and the specific heat capacity of the water in each?

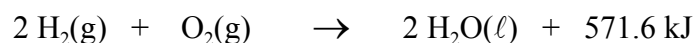
	Heat capacity	Specific Heat Capacity
(A)	$\text{H}_2\text{O}_{\text{bathtub}} = \text{H}_2\text{O}_{\text{teacup}}$	$\text{H}_2\text{O}_{\text{bathtub}} = \text{H}_2\text{O}_{\text{teacup}}$
(B)	$\text{H}_2\text{O}_{\text{bathtub}} = \text{H}_2\text{O}_{\text{teacup}}$	$\text{H}_2\text{O}_{\text{bathtub}} < \text{H}_2\text{O}_{\text{teacup}}$
(C)	$\text{H}_2\text{O}_{\text{bathtub}} > \text{H}_2\text{O}_{\text{teacup}}$	$\text{H}_2\text{O}_{\text{bathtub}} = \text{H}_2\text{O}_{\text{teacup}}$
(D)	$\text{H}_2\text{O}_{\text{bathtub}} > \text{H}_2\text{O}_{\text{teacup}}$	$\text{H}_2\text{O}_{\text{bathtub}} < \text{H}_2\text{O}_{\text{teacup}}$

33. If 9.54 kJ of heat is required to raise the temperature of 225.0 g of a substance from  $20.5^\circ\text{C}$  to  $45.0^\circ\text{C}$ , what is the specific heat capacity of the substance?
- (A)  $0.00173 \text{ J/g}^\circ\text{C}$   
 (B)  $0.578 \text{ J/g}^\circ\text{C}$   
 (C)  $1.04 \text{ J/g}^\circ\text{C}$   
 (D)  $1.73 \text{ J/g}^\circ\text{C}$

34. Given the specific heat capacity of  $\text{H}_2(\text{g})$  is  $14.3 \text{ J/g} \cdot ^\circ\text{C}$ , how much energy is absorbed when  $2.50 \text{ g}$  of  $\text{H}_2(\text{g})$  is heated from  $17.0 \text{ }^\circ\text{C}$  to  $23.0 \text{ }^\circ\text{C}$ ?

- (A)  $2.15 \times 10^2 \text{ J}$
- (B)  $4.30 \times 10^2 \text{ J}$
- (C)  $2.15 \times 10^5 \text{ J}$
- (D)  $4.30 \times 10^5 \text{ J}$

35. How much heat is produced when  $5.550$  moles of  $\text{H}_2(\text{g})$  is consumed in the reaction below?

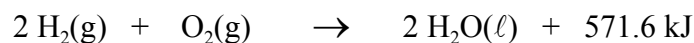


- (A)  $285.8 \text{ kJ}$
- (B)  $571.6 \text{ kJ}$
- (C)  $1586 \text{ kJ}$
- (D)  $3172 \text{ kJ}$

36. Which illustrates the first law of thermodynamics?

- (A)  $q_{\text{system}} = -q_{\text{surroundings}}$
- (B)  $q_{\text{system}} = q_{\text{surroundings}}$
- (C)  $\Delta T_{\text{system}} = \Delta T_{\text{surroundings}}$
- (D)  $\Delta T_{\text{system}} = -\Delta T_{\text{surroundings}}$

37. Which describes the reaction below?



	Type	$\Delta H$
(A)	endothermic	negative
(B)	endothermic	positive
(C)	exothermic	negative
(D)	exothermic	positive

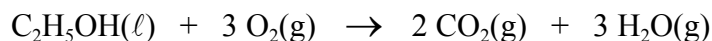
38. Which phase change has occurred for a  $5.00 \text{ g}$  sample of  $\text{H}_2\text{O}$  if it has absorbed  $1.67 \text{ kJ}$  of heat?

- (A)  $\text{H}_2\text{O}(\ell) \rightarrow \text{H}_2\text{O}(\text{s})$
- (B)  $\text{H}_2\text{O}(\text{s}) \rightarrow \text{H}_2\text{O}(\ell)$
- (C)  $\text{H}_2\text{O}(\text{g}) \rightarrow \text{H}_2\text{O}(\ell)$
- (D)  $\text{H}_2\text{O}(\ell) \rightarrow \text{H}_2\text{O}(\text{g})$

39. What is true of the enthalpy change for a chemical reaction?

- (A) always decreases
- (B) always increases
- (C) is dependent on the pathway
- (D) is independent of the pathway

40. Given the information below, what is the molar enthalpy of combustion for ethanol?



Species	$\Delta H^\circ_f$ (kJ/mol)
$\text{C}_2\text{H}_5\text{OH}(\ell)$	-278
$\text{CO}_2(\text{g})$	-394
$\text{H}_2\text{O}(\text{g})$	-242

- (A) -1236 kJ  
(B) -358 kJ  
(C) 358 kJ  
(D) 1236 kJ
41. In a redox reaction which best describes what happens to the reducing agent?
- (A) forms a negative ion  
(B) forms a positive ion  
(C) gains electrons  
(D) loses electrons
42. Which type of reaction is **not** a redox reaction?
- (A) double replacement  
(B) simple composition  
(C) simple decomposition  
(D) single replacement
43. What is the oxidation number of S in  $\text{MgS}_2\text{O}_6$ ?
- (A) +3  
(B) +5  
(C) +6  
(D) +7
44. What is true in the reaction below?
- $$\text{Ga}^{3+}(\text{aq}) + \text{Rb}(\text{s}) \rightarrow \text{Rb}^{3+}(\text{aq}) + \text{Ga}$$
- (A) Ga loses electrons.  
(B)  $\text{Ga}^{3+}$  is an oxidizing agent.  
(C) Rb gains electrons.  
(D)  $\text{Rb}^{3+}$  is a reducing agent.
45. Which species is reduced in the reaction below?
- $$5 \text{Ag} + \text{MnO}_4^- + 8 \text{H}^+ \rightarrow 5 \text{Ag}^+ + \text{Mn}^{2+} + 4 \text{H}_2\text{O}$$
- (A) Ag  
(B) H  
(C) Mn  
(D) O

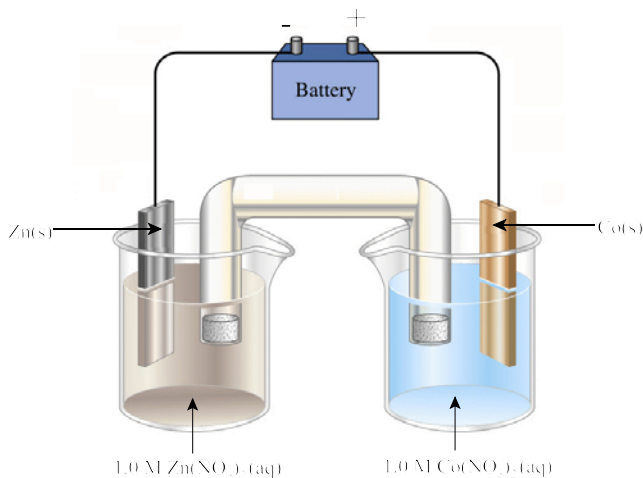
46. In an electrochemical cell, what does the salt bridge allow to happen?

- (A) migration of ions
- (B) movement of electrons
- (C) non-spontaneous reaction
- (D) reaction with water

47. Which describes an operating electrochemical cell?

	$E^\circ$	Direction of Electron Flow
(A)	negative	anode to cathode
(B)	negative	cathode to anode
(C)	positive	anode to cathode
(D)	positive	cathode to anode

48. In the electrolytic cell below, what is true of the  $\text{Co}^{2+}(\text{aq})$  movement and the mass of the zinc electrode?



	$\text{Co}^{2+}$ movement	Mass of Zinc Electrode
(A)	toward Co	decreases
(B)	toward Co	increases
(C)	toward Zn	decreases
(D)	toward Zn	increases

49. Which combination will react spontaneously?

- (A)  $\text{Cu} + \text{Ni}^{2+}$
- (B)  $\text{I}^- + \text{Cu}^{2+}$
- (C)  $\text{Pb}^{2+} + \text{Hg}$
- (D)  $\text{Zn}^{2+} + \text{Mg}$

50. For the electrochemical cell below the  $E^\circ_{\text{cell}}$  is 0.94 V.



What is the  $E^\circ$  value for  $\text{X}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{X(s)}$ ?

- (A) -0.66 V
- (B) -0.14 V
- (C) 0.14 V
- (D) 0.66 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

6% 51.(a) Use the table below to answer the following questions.

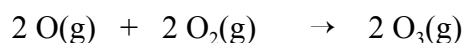
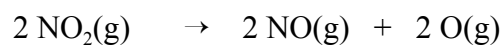
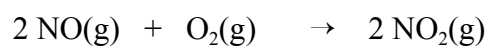
Reaction Mechanism	Rate	$\Delta H$ (kJ)
$2 \text{NO}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2 \text{NO}_2(\text{g})$	very fast	-116
$2 \text{NO}_2(\text{g}) \rightarrow 2 \text{NO}(\text{g}) + 2 \text{O}(\text{g})$	very slow	-175
$2 \text{O}(\text{g}) + 2 \text{O}_2(\text{g}) \rightarrow 2 \text{O}_3(\text{g})$	slow	88

- (i) What is the enthalpy for the overall reaction?
- (ii) Identify the reaction intermediate(s) and/or catalyst(s) present.
- Reaction Intermediate(s):
- Catalyst(s):
- (iii) Sketch a clearly labelled potential energy diagram for this reaction mechanism.

**Value**

3% 51.(b) All Canadian automobiles are equipped with catalytic converters to improve air quality.

- (i) Using the mechanism below for ozone production, describe how catalytic converters decrease ground level ozone concentrations.



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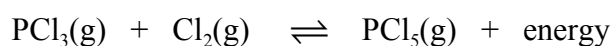
- (ii) Describe one way to improve the design of a catalytic converter that will increase its ability to reduce air pollution.

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4% (c) The system below is at equilibrium.



- (i) If the gases are in a sealed container, explain the effect increasing the volume would have on the equilibrium position.

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- (ii) Explain what effect increasing the temperature of the reaction vessel would have on the value of  $K_{\text{eq}}$  for this reaction.

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**Value**

4% 52.(a) A primary standard of  $\text{Na}_2\text{CO}_3(\text{s})$  is used to determine the concentration of a hydrochloric acid solution. In the first trial a solution containing 0.5012 g of  $\text{Na}_2\text{CO}_3(\text{s})$  required 21.35 mL of  $\text{HCl}(\text{aq})$  to reach the equivalence point.



(i) Based on this trial, what is the concentration of  $\text{HCl}(\text{aq})$ ?

(ii) Why is it important to perform more than one trial?

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2% (b) What is happening at a molecular level, to explain why the pH of 1.0 mol/L  $\text{CH}_3\text{COOH}(\text{aq})$  is greater than the pH of 1.0 mol/L  $\text{H}_2\text{COOH}(\text{aq})$ ?

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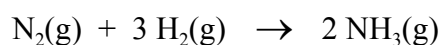


**Value**

3% 53.(a) 5.50 g of NaOH(s) is dissolved in 175 mL of water in a coffee cup calorimeter. If the temperature of the water increased by 2.1 °C, calculate the molar heat of solution for NaOH(s).

3% (b) Calculate the total energy required to heat 225 g of H<sub>2</sub>O from -25.0 °C to 80.0 °C. ( $c_{\text{ice}} = 2.01 \text{ J/g}\cdot\text{°C}$ )

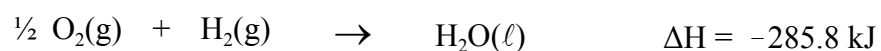
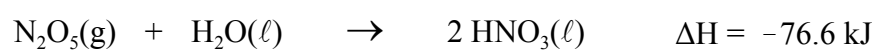
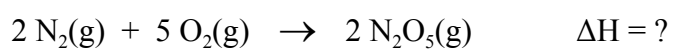
3% (c) Using the data below, calculate  $\Delta H$  for



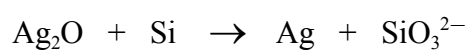
Bond	Average Bond Energy (kJ)
H-H	436
N≡N	945
N-H	360

**Value**

4% 53.(d) Using the data below, calculate the enthalpy change for the following reaction.



3% 54.(a) Under acidic conditions, balance the redox reaction below.



**Value**

4% 54.(b) An electrolytic cell has a zinc strip anode and a zinc strip cathode placed in a solution of zinc sulfate. A current of 0.500 A is supplied for 900.0 seconds.

(i) What mass of zinc is electroplated?

(ii) Explain one reason why the actual observation could be less than the predicted value.

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3% (c) Three different elements were combined with solutions of their anions. The results are shown in the table below.

Element	Anion		
	A <sup>-</sup> (aq)	B <sup>-</sup> (aq)	C <sup>-</sup> (aq)
A	-	no reaction	no reaction
B	reaction	-	reaction
C	reaction	no reaction	-

Which is the correct order of anions from strongest to weakest reducing agent? Explain.

*strongest* → *weakest*

\_\_\_\_\_ → \_\_\_\_\_ → \_\_\_\_\_

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