PART I
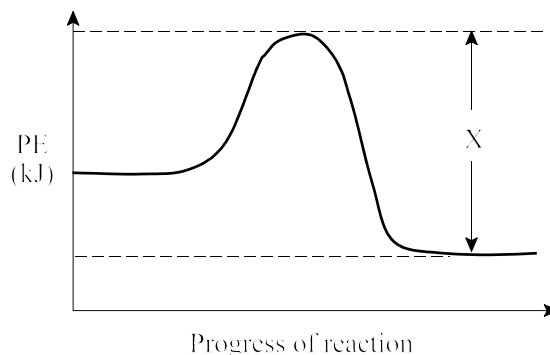## Total Value: 50%

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

1. What does X represent in the diagram below?

   (A) activation energy for the forward reaction
   (B) activation energy for the reverse reaction
   (C) heat of reaction for the forward reaction
   (D) heat of reaction for the reverse reaction

2. Which increases the reaction rate?

   (A) decreasing the frequency of collisions
   (B) decreasing ΔH for the reaction
   (C) increasing the frequency of collisions
   (D) increasing ΔH for the reaction

3. Which observation best supports the Kinetic Molecular Theory?

   (A) Acetic acid odour is detected from across the room.
   (B) Liquid water freezes at 0°C under standard conditions.
   (C) Nitrogen dioxide gas is dark brown in colour.
   (D) When burned, butane produces more heat per mole than propane.

4. What is the high energy, unstable chemical species that exists in the transition from reactants to products?

   (A) activated complex
   (B) catalyst
   (C) inhibitor
   (D) reaction intermediate

5. What is the value of ΔH for the forward reaction if its activation energy is 20.0 kJ and the activation energy of the reverse reaction is 30.0 kJ?

   (A) -50.0 kJ
   (B) -10.0 kJ
   (C) 10.0 kJ
   (D) 50.0 kJ

6. What affect would increasing the surface area of a solid reactant have on a system approaching equilibrium?

   (A) decreases the rate of the forward reaction
   (B) decreases the time to reach equilibrium
   (C) increases the equilibrium concentration of products
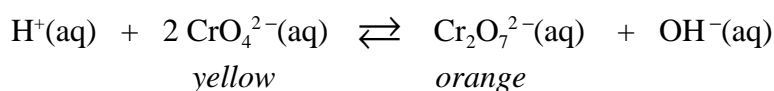   (D) increases the equilibrium concentration of reactants

7.   For the reaction mechanism below, increasing the concentration of which species would have the greatest effect on the overall reaction rate?

$$X + Y \rightarrow 2Z \quad \text{slow}$$
$$Z + 2W \rightarrow U \quad \text{fast}$$
$$Z + U \rightarrow V \quad \text{fast}$$
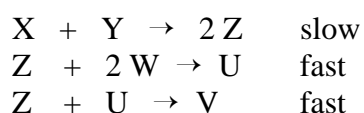
(A)   U
(B)   V
(C)   Y
(D)   Z

8.   The table below describes two different reactions in which Reaction 1 is faster. What accounts for this observation?

|	Reaction 1	Reaction 2
Reactants	$Fe^{2+}(aq) + MnO_4^-(aq)$	$MnO_4^-(aq) + H_2C_2O_4(aq)$
Temperature	20 °C	40 °C
Concentration	0.5 mol/L solutions	1.0 mol/L solutions

(A)   nature of reactants
(B)   solution concentration
(C)   surface area
(D)   temperature

9.   The equilibrium system below is in a test tube at room temperature. When five drops of $Fe(NO_3)(aq)$ is added, a precipitate forms.

$$H^+(aq) + 2CrO_4^{2-}(aq) \rightleftarrows Cr_2O_7^{2-}(aq) + OH^-(aq)$$
$$\qquad\qquad yellow \qquad\qquad orange$$

What is the colour of the solution and how does the concentration of $OH^-(aq)$ change?

	colour	$[OH^-(aq)]$
(A)	orange	decrease
(B)	orange	increase
(C)	yellow	decrease
(D)	yellow	increase

10.   What happens to $[O_2(g)]$ and $[H_2O(g)]$ in the equilibrium below if the system is heated?

$$4HCl(aq) + O_2(g) \rightleftarrows 2H_2O(g) + 2Cl_2(g) \qquad \Delta H = +113 \text{ kJ}$$
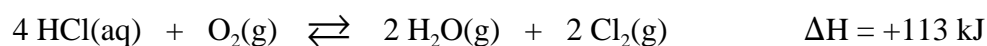
	$[O_2(g)]$	$[H_2O(g)]$
(A)	decreases	decreases
(B)	decreases	increases
(C)	increases	decreases
(D)	increases	increases

11. Given the equilibrium concentrations;

$[CO(g)] = 0.105$ mol/L, $[H_2(g)] = 0.250$ mol/L, and $[CH_3OH(g)] = 0.00261$ mol/L, what is the value of K_{eq} for the equilibrium below?

$$CO(g) + 2 H_2(g) \rightleftharpoons CH_3OH(g)$$
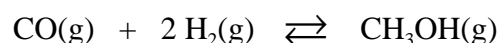
(A)   0.0994
(B)   0.398
(C)   2.51
(D)   10.0

12. What happens to the equilibrium below when $NO(g)$ is added to the system?

$$2 NO(g) + Cl_2(g) \rightleftharpoons 2 NOCl(g)$$
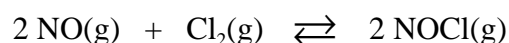
	Shift	$[Cl_2(g)]$
(A)	left	decreases
(B)	left	increases
(C)	right	decreases
(D)	right	increases

13. A solution of which pH would make red litmus paper turn blue?

(A)   2
(B)   4
(C)   6
(D)   8

14. Which is the most recent definition of an acid?

(A)   Arrhenius
(B)   Brønsted–Lowry
(C)   modified Arrhenius
(D)   operational

15. If their concentrations are equal, which solution will show the highest electrical conductivity?

(A) H_3BO_3 (aq)
(B)   HCl (aq)
(C) H_2CO_3 (aq)
(D) $H_2C_2O_4$ (aq)

16. Which substance, when added to $H_2SO_4(aq)$, would produce a precipitate and make the solution less acidic?

(A) $Ca(NO_3)_2$
(B) $LiNO_3$
(C)   NaOH
(D) $Sr(OH)_2$

17. The table below lists four unknown acids. The pH of a 0.10 mol/L solution for each acid is given. Which conjugate base would have the lowest K_b?

Acid	pH
HW(aq)	2.32
HX(aq)	1.41
HY(aq)	1.00
HZ(aq)	5.00

   (A) W^-(aq)
   (B) X^-(aq)
   (C) Y^-(aq)
   (D) Z^-(aq)

18. What is the K_a expression for $HMnO_4$(aq)?

   (A) $\dfrac{[H_3O^+][MnO_4^-]}{[H_2O][HMnO_4]}$

   (B) $\dfrac{[H_2O][HMnO_4]}{[H_3O^+][MnO_4^-]}$

   (C) $\dfrac{[HMnO_4]}{[H_3O^+][MnO_4^-]}$

   (D) $\dfrac{[H_3O^+][MnO_4^-]}{[HMnO_4]}$

19. In the equilibrium below, which two species act as Brønsted-Lowry bases?

$$HS^-(aq) \;+\; H_3BO_3(aq) \;\rightleftharpoons\; H_2BO_3^-(aq) \;+\; H_2S(aq)$$

   (A) H_3BO_3 and $H_2BO_3^-$
   (B) H_3BO_3 and H_2S
   (C) HS^- and $H_2BO_3^-$
   (D) HS^- and H_2S

20. What is the pOH of a solution if the pH is 2.0?

   (A) 0.01
   (B) 0.02
   (C) 2.0
   (D) 12.0

21. What is a substance of known purity and molecular mass used to prepare a solution with a precise concentration?

   (A) buffer
   (B) indicator
   (C) primary standard
   (D) standard solution

22.   What is the pH of a 0.050 mol/L $Cu(OH)_2$ solution?

        (A)   1.00
        (B)   1.30
        (C)   12.70
        (D)   13.00

23.   Which best describes $[OH^-]$ and $[H_3O^+]$ in a sample of pure water at 25.0°?

	$[OH^-]$	$[H_3O^+]$
(A)	1.0×10^{-7} mol/L	1.0×10^{-7} mol/L
(B)	1.0×10^{-7} mol/L	$< 1.0 \times 10^{-7}$ mol/L
(C)	$< 1.0 \times 10^{-7}$ mol/L	1.0×10^{-7} mol/L
(D)	$> 1.0 \times 10^{-7}$ mol/L	$> 1.0 \times 10^{7}$ mol/L

24.   The data below was obtained from a titration of acetic acid with sodium hydroxide to the
        equivalence point. What most likely caused the result in trial 3?

Trial	NaOH required (mL)
1	12.63
2	12.61
3	14.35
4	12.62

        (A)   All the acid was removed from the pipette.
        (B)   Four drops of indicator was used instead of two.
        (C)   The pipette was rinsed with water before use.
        (D)   The reaction flask was rinsed with water.

25.   Which indicator should be used to detect the equivalence point in a titration of
        hydrofluoric acid with sodium hydroxide?

        (A)   bromocresol green
        (B)   methyl red
        (C)   orange IV
        (D)   thymolphthalein

26.   Which titration could result in pH = 4.0 at the equivalence point?

	Sample	Titrant
(A)	HBr	LiOH
(B)	HBr	NaCN
(C)	H_2CO_3	LiOH
(D)	H_2CO_3	NaCN

27. What is the [OH⁻] for an aqueous solution with pH = 3.25?

    (A) 1.8×10^{-11} mol/L
    (B) 5.6×10^{-4} mol/L
    (C)   0.51 mol/L
    (D)   1.0 mol/L

28. Which is a closed system?

    (A)   burning candle
    (B)   halogen lightbulb
    (C)   hot water in a sink
    (D)   ripening banana

29. Which involves the greatest energy change?

    (A)   chemical reaction
    (B)   nuclear reaction
    (C)   phase change
    (D)   physical change

30. When the contents of a cold pack are reacted, a cooling effect is observed. How does the energy of the pack and the energy of the surroundings change to get this cooling effect?

	Energy of the pack	Energy of the surroundings
(A)	decreases	decreases
(B)	decreases	increases
(C)	increases	decreases
(D)	increases	increases

31. Which is true for the energy change of ice when it melts at 0 °C?

	Kinetic Energy	Potential Energy
(A)	constant	decreases
(B)	constant	increases
(C)	increases	decreases
(D)	increases	increases

32. Which best describes the reaction below?

$$C(s) + O_2(g) \rightarrow CO_2(g) + 393.5 \text{ kJ}$$

|	Type of reaction	Potential energy of products
(A)	endothermic	greater than reactants
(B)	endothermic	less than reactants
(C)	exothermic	greater than reactants
(D)	exothermic	less than reactants

33. A 10.0 g sample that is 75.0% C_8H_{18} and 25.0% C_2H_5OH is completely combusted. Given the fuel values below, how much energy was released?

Substance	Fuel Value
C_8H_{18}	47.7 kJ/g
C_2H_5OH	29.66 kJ/g

    (A)   34.2 kJ
    (B)   77.4 kJ
    (C)   387 kJ
    (D)   432 kJ

34. The molar enthalpy of combustion for glucose, $C_6H_{12}O_6(s)$ (molar mass = 180.18 g/mol), is -2808 kJ/mol. What mass of glucose must be burned to release 2430 kJ of energy?

    (A)   101 g
    (B)   156 g
    (C)   321 g
    (D)   561 g

35. How much energy is required to heat 5.0 g of aluminum from 20.0 $^{\circ}C$ to 100.0 $^{\circ}C$? ($c_{Al} = 0.900\ J/_{g\cdot ^{\circ}C}$)

    (A)   13 J
    (B)   17 J
    (C)   360 J
    (D)   450 J

36. The graph below represents the heating curve of a substance that starts as a solid below its freezing point. What is the melting point of this substance?
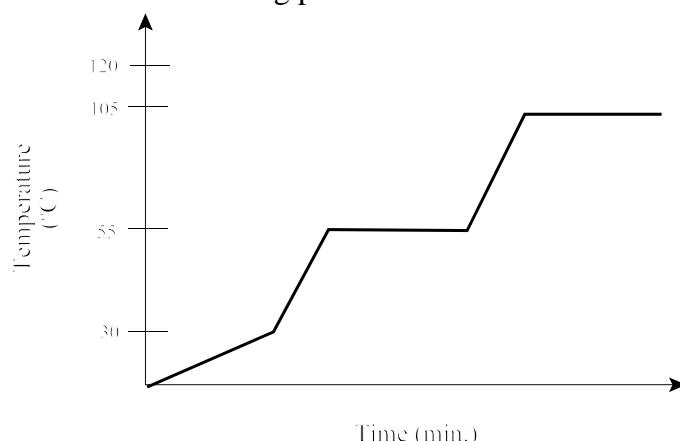
    (A)   30 °C
    (B)   55 °C
    (C)   105 °C
    (D)   120 °C

37. Water is heated from ice at 0.0 °C to vapour at 110.0 °C. When does the water experience the greatest change in potential energy?

    (A)   at 0.0 °C
    (B)   0.0 °C to 100.0 °C
    (C)   at 100.0 °C
    (D)   100.0 °C to 110.0 °C

38. Initially a large candle is lit at one end. A student decides to light the other end so that she is "burning the candle at both ends." What has doubled in this system?

   (A) amount of energy released
   (B) fuel value of the candle
   (C) molar enthalpy of combustion
   (D) temperature of the candle

39. Given the data below, what is the ΔH_{rxn} for: $4\ FeO(s)\ +\ O_2(g)\ \rightarrow\ 2\ Fe_2O_3(s)$?

Substance	ΔH_f (kJ/mol)
$FeO(s)$	-268
$Fe_2O_3(s)$	-823

   (A) -574 kJ
   (B) -555 kJ
   (C) 555 kJ
   (D) 574 kJ

40. A student attempting to determine the molar enthalpy of combustion for ethanol uses an alcohol burner to heat a tin can which is half full of water. In calculating the energy absorbed by the water, the result obtained was lower than the accepted value. Which had the least affect on the error?

   (A) amount of soot on the can
   (B) amount of water in the can
   (C) heat absorbed by the can
   (D) distance between the burner and can

41. Which is a redox reaction?

   (A) $Ag_2CrO_4\ \rightarrow\ 2\ Ag^+\ +\ CrO_4^{2-}$
   (B) $AgNO_3\ +\ NaCl\ \rightarrow\ AgCl\ +\ NaNO_3$
   (C) $2\ H_2\ +\ O_2\ \rightarrow\ 2\ H_2O$
   (D) $H_3O^+\ +\ OH^-\ \rightarrow\ 2\ H_2O$

42. What is the oxidation number of Mo in Mg_2MoO_4?

   (A) +3
   (B) +4
   (C) +6
   (D) +7

43. Which cells are contained in secondary batteries?

   (A) electrolytic
   (B) fuel
   (C) galvanic
   (D) rechargeable

44. Which factor will affect the cell potential of a galvanic cell?

   (A) concentration of the electrolyte
   (B) electrolyte used in salt bridge
   (C) mass of the electrode
   (D) volume of electrolyte

45. Which half reaction is balanced?

(A) $ClO^- + H_2O + 2e^- \rightarrow Cl^- + 2\,OH^-$
(B) $NO_2^- + H_2O + 2e^- \rightarrow 2H^+ + NO_3^-$
(C) $2\,NO_3^- + 4\,H^+ + 2e^- \rightarrow N_2O + 2\,H_2O$
(D) $SO_4^{2-} + 8\,H^+ + 6e^- \rightarrow H_2S + 4\,H_2O$

46. If the reaction below occurs in an electrochemical cell, what is the anode?

$$Fe(s) + Cd^{2+}(aq) \rightarrow Fe^{2+}(aq) + Cd(s)$$
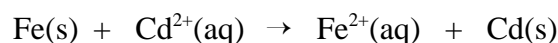
(A) Cd
(B) Cd^{2+}
(C) Fe
(D) Fe^{2+}
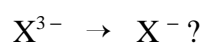
47. Which reactants would produce a spontaneous reaction?

(A) $Ca^{2+}(aq)$ and $Zn(s)$
(B) $Cu^{2+}(aq)$ and $Ag(s)$
(C) $Co^{2+}(aq)$ and $Al(s)$
(D) $Zn^{2+}(aq)$ and $Cd(s)$

48. Which is an electrolytic cell reaction?

(A) $Ag^+(aq) + Sn^{2+}(aq) \rightarrow Ag(s) + Sn^{4+}(aq)$
(B) $Cd^{2+}(aq) + Pb(s) \rightarrow Cd(s) + Pb^{2+}(aq)$
(C) $Cu^{2+}(aq) + Cr^{2+}(aq) \rightarrow Cu(s) + Cr^{3+}(aq)$
(D) $Fe^{2+}(aq) + Zn(s) \rightarrow Fe(s) + Zn^{2+}(aq)$

49. How would the reaction below be balanced:

$$X^{3-} \rightarrow X^- ?$$

(A) add 2 e^- to the product side
(B) add 2 e^- to the reactant side
(C) add 4 e^- to the product side
(D) add 4 e^- to the reactant side

50. Given the redox reaction below, what is E^O for the reduction of X^{2+}?

$$2\,Al(s) + 3\,X^{2+}(aq) \rightarrow 2\,Al^{3+}(aq) + 3\,X(s) \qquad E^o = 1.30\ V$$
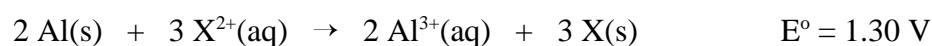
(A) - 2.96
(B) - 0.36
(C) +0.36
(D) +2.96

PART II
Total Value: 50%

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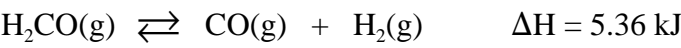
Value

4%   51.(a) Use the table below to answer the following questions.

Reaction Mechanism	ΔH
$Fe^{3+} + H_2O_2 \rightarrow FeOH^{3+} + HO$	- 286.1 kJ
$HO + H_2O_2 \rightarrow H_2O + HO_2$	+ 270.4 kJ
$FeOH^{3+} + HO_2 \rightarrow Fe^{3+} + H_2O + O_2$	- 556.7 kJ

(i)   Write the equation for the overall net reaction.

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

Reaction Intermediate(s):

Catalyst(s):

(iii)   What is the enthalpy for the overall reaction?

2%   (b)   The system below is at equilibrium.

$$H_2CO(g) \rightleftharpoons CO(g) + H_2(g) \qquad \Delta H = 5.36 \text{ kJ}$$

What effect would increasing the temperature have on the value of K_{eq} for this reaction? Justify your answer.

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51.(c) Mixtures of hydrogen gas and carbon monoxide are placed in two separate flasks. One flask is at 1000.0 °C and the other is at 1200.0 °C. The graph below shows the change in methane concentration over time for each flask.

$$3\,H_2(g) \;+\; CO(g) \;\rightleftarrows\; CH_4(g) \;+\; H_2O(g) \qquad \Delta H = -206\ kJ$$
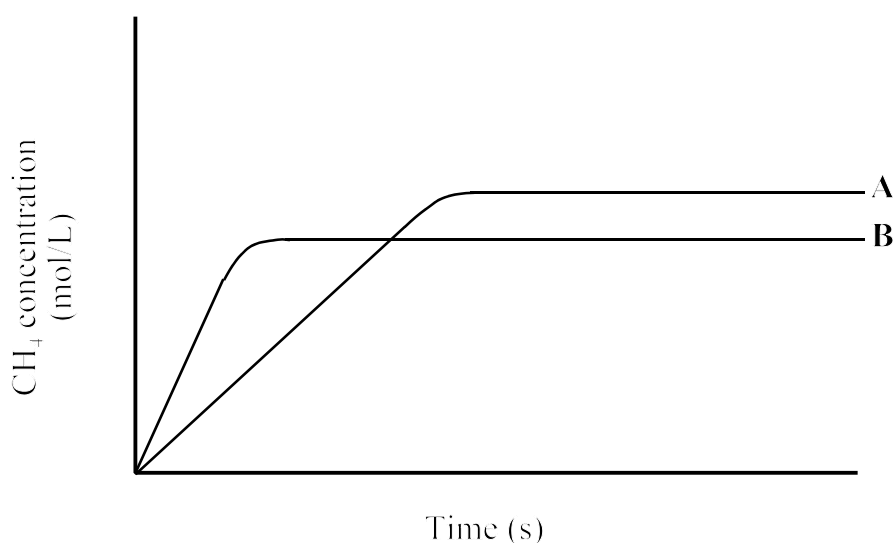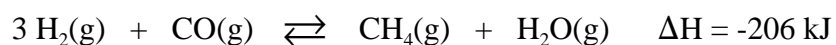
(i) Mark an "X" on each line in the graph, where equilibrium is first established.

(ii) Which temperature condition, 1000.0 °C or 1200.0 °C, is represented by line A in the graph? Provide two reasons for your answer.

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Value

3%   51.(d) The equilibrium below occurs when nitrogen monoxide is placed in a closed container and decomposes.

$$2\,NO(g) \;\rightleftarrows\; N_2(g) \;+\; O_2(g)$$

When 0.250 mol of NO(g) is placed in a sealed 1.0 L container at a particular temperature, 40.0% of it decomposes. Calculate the equilibrium constant at this temperature.

5%   52.(a) Calculate the pH of a 0.025 mol/L solution of nitrous acid given the K_a for $HNO_2(aq)$ is 7.2×10^{-4}.

3%   52.(b) The concentration of a solution of arsenic acid, H_3AsO_4(aq) is determined by titrating it with sodium hydroxide, NaOH(aq).

   (i)   Write the equation for the overall reaction.

   (ii)   Draw and label a titration curve for the complete titration.

3%   (c) A titration was performed by adding 0.115 mol/L NaOH(aq) to a 25.00 mL sample of H_2SO_4(aq). Using the data below, calculate the concentration of H_2SO_4(aq).

reading (mL)	Trial 1	Trial 2	Trial 3
final reading	17.05	28.00	39.00
initial reading	4.00	17.05	28.00
volume added	13.05	10.95	11.00

2%   52.(d) The table below shows the results of tests performed on four 0.10 mol/L unknown
          solutions. Use this data to determine which solution is NaOH(aq) and which is
          NaCl(aq). Justify your answer.

Solution	Conductivity of Solution	Colour with Bromothymol Blue
A	good	blue
B	good	yellow
C	good	green
D	poor	blue

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2%   (e) A piece of magnesium is placed in both hydrochloric acid, HCl (aq), and acetic
          acid, CH$_3$COOH (aq), according to the information below. Compare both reactions
          in terms of reaction rate and amount of hydrogen gas produced. Justify your
          answer.

Reaction 1

$Mg(s) + 2 HCl(aq) \rightarrow MgCl_2(aq) + 2 H_2(g)$

5.0 g Mg

150 mL of 0.10 mol/L acid

Reaction 2

$Mg(s) + 2 CH_3COOH(aq) \rightarrow Mg(CH_3COO)_2(aq) + 2 H_2(g)$

5.0 g Mg

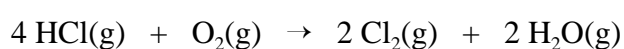150 mL of 0.10 mol/L acid

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2%   53.(a) A butane torch can be used to determine the heat capacity of antifreeze. Butane, C_4H_{10}, has a molar heat of combustion of 802.3 kJ/mol. List the laboratory equipment and the data needed to determine the specific heat capacity of antifreeze solution.
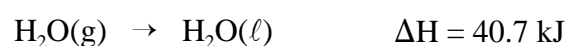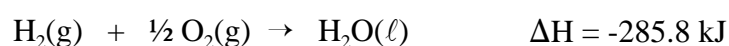
Lab Equipment: _____

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Data needed: _____

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4%   (b)   Calculate the enthalpy change for the following reaction:

$$4\ HCl(g)\ +\ O_2(g)\ \rightarrow\ 2\ Cl_2(g)\ +\ 2\ H_2O(g)$$

Given the following information:

$$H_2(g)\ +\ Cl_2(g)\ \rightarrow\ 2HCl(g) \qquad \Delta H = -185\ kJ$$

$$H_2(g)\ +\ \tfrac{1}{2}\,O_2(g)\ \rightarrow\ H_2O(\ell) \qquad \Delta H = -285.8\ kJ$$

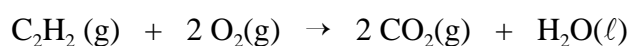$$H_2O(g)\ \rightarrow\ H_2O(\ell) \qquad \Delta H = 40.7\ kJ$$

2%   (c)   A 1.50 g sample of granola bar is placed in a bomb calorimeter with a heat capacity of 10.2 kJ/°C. When the bar is completely burned the temperature of the calorimeter and its contents increased by 3.10 °C. What is the fuel value of the bar?

53.(d) The reaction below shows the combustion of ethyne.

$$C_2H_2 (g) + 2 O_2(g) \rightarrow 2 CO_2(g) + H_2O(\ell)$$

(i) Use the bond energies in the table below to calculate the molar heat of reaction for ethyne.

Bond	Energy (kJ)
O – H	460
C – H	338
C $\equiv$ C	891
C = O	745
O = O	498

(ii) A calorimetry experiment performed by a student determined the molar heat of this reaction to be -1289 kJ/moL. Give two reasons why there is a difference in the ΔH value obtained from calorimetry and the value obtained from bond energies?

4%   54.(a) What is the mass of magnesium produced by the electrolysis of molten magnesium chloride, $MgCl_2$, if a 250.0 mA current passes for 1.50 hours?

4%   (b)   Balance the redox reaction below for basic conditions.

$MnO_4^-(aq) + CN^-(aq) \rightarrow MnO_2(s) + OCN^-(aq)$
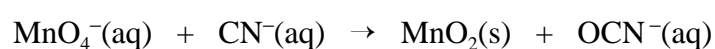
2%   (c)   Pyrometallurgy and hydrometallurgy are methods of isolating metals from its ore. Which of these processes would you propose for a new nickel smelter being built in Newfoundland and Labrador? Justify your answer.