## Part I
## Total Value: 50%

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

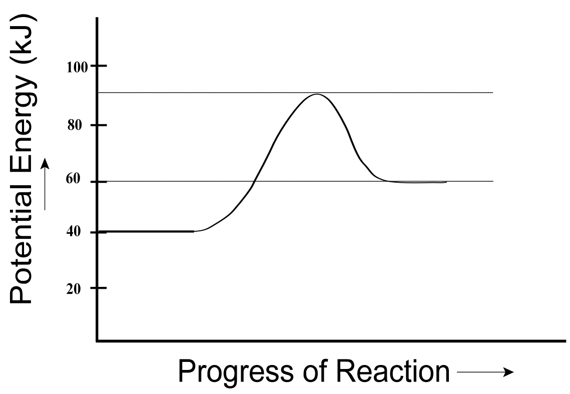
1. Which observation can be explained using the kinetic molecular theory?

✔ (A) A basketball is inflated with air.
(B) Butane $C_4H_{10}$ burns faster than pentane $C_5H_{12}$.
(C) Powdered coal is more explosive than lumps of coal.
(D) Silver metal reacts slower than aqueous silver nitrate.

2. Which factor best explains why the combustion of candle wax, $C_{25}H_{52}$, is slower than the combustion of decane, $C_{10}H_{22}$?

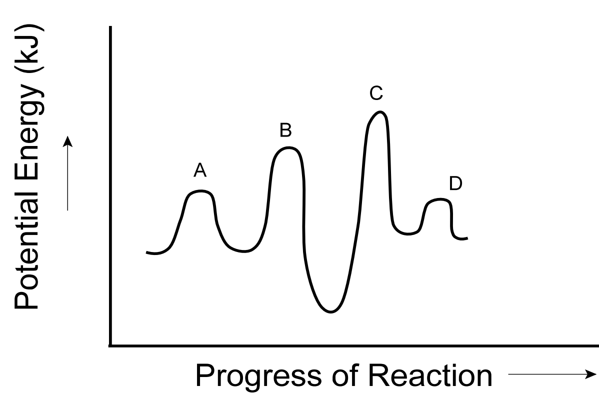
(A) concentration
✔ (B) nature of reactants
(C) pressure
(D) temperature

3. For the diagram below, what is the activation energy for the reverse reaction?




(A) 20 kJ
✔ (B) 30 kJ
(C) 40 kJ
(D) 50 kJ

4. What is the rate determining step in the mechanism below?




(A) A
(B) B
✔ (C) C
(D) D

5. Using the mechanism below, which species is the catalyst?

| | | | |
|---|---|---|---|
| Step 1: | $2\ NO(g) + O_2(g)$ | $\rightarrow$ | $2\ NO_2(g)$ |
| Step 2: | $2\ NO_2(g)$ | $\rightarrow$ | $2\ NO(g) + 2\ O(g)$ |
| Step 3: | $2\ O(g) + 2\ O_2(g)$ | $\rightarrow$ | $2\ O_3(g)$ |

✔ (A) $NO(g)$
(B) $NO_2(g)$
(C) $O(g)$
(D) $O_2(g)$

6. Given the table below, order the reaction trials from fastest to slowest.

| Trial # | Concentration (mol/L) | Temperature (°C) |
|---|---|---|
| 1 | 0.020 | 30 |
| 2 | 0.020 | 20 |
| 3 | 0.20 | 50 |
| 4 | 0.20 | 40 |

fastest $\rightarrow$ slowest

(A) 1 → 2 → 3 → 4
(B) 2 → 1 → 4 → 3
✔ (C) 3 → 4 → 1 → 2
(D) 4 → 3 → 2 → 1

7. Which change will affect the value of K in the equilibrium system below?

$$2\ NO_2(g) \rightleftharpoons 2\ NO(g) + O_2(g) \qquad \Delta H = 54\ kJ$$

✔ (A) decreasing temperature
(B) decreasing volume
(C) increasing [NO]
(D) increasing $[NO_2]$

8. Which change in the equilibrium below would result in the highest concentration of $IF_3$?

$$3\ I_2(g) + 4\ F_2(g) \rightleftharpoons 2\ IF_3(g) + I_4F_2(g) + 34.2\ kJ$$

(A) decreasing $[I_2]$
✔ (B) decreasing volume
(C) increasing $[I_4F_2]$
(D) increasing temperature

9. Which is true, for the equilibrium as written, if the system changes from blue to pink when placed in an ice bath?

$$\underset{pink}{Co(H_2O)_6^{2+}(aq)} + 4\,Cl^-(aq) \rightleftharpoons \underset{blue}{CoCl_4^{2-}(aq)} + 6\,H_2O(\ell)$$

| | | Reaction Type | ΔH |
|---|---|---|---|
| | (A) | endothermic | negative |
| ✔ | (B) | endothermic | positive |
| | (C) | exothermic | negative |
| | (D) | exothermic | positive |

10. Which K value indicates the highest concentration of reactants?

✔ (A) $1.9 \times 10^{-8}$
(B) $1.3 \times 10^{-7}$
(C) $2.6 \times 10^{7}$
(D) $3.9 \times 10^{8}$

11. What is the equilibrium constant expression for the system below?

$$2\,C(s) + 2\,H_2O(g) \rightleftharpoons CH_4(g) + CO_2(g)$$

✔ (A) $\dfrac{[CH_4][CO_2]}{[H_2O]^2}$

(B) $\dfrac{[CH_4][CO_2]}{[C]^2[H_2O]^2}$

(C) $\dfrac{[H_2O]^2}{[CH_4][CO_2]}$

(D) $\dfrac{[C]^2[H_2O]^2}{[CH_4][CO_2]}$

12. 0.100 mol of $PCl_3$, $Cl_2$, and $PCl_5$ are each introduced into the same 1.0 L evacuated flask. What is true of the concentration of each substance as the equilibrium below is established?

$$PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g) \qquad K_{eq} = 0.45$$

| | | $[PCl_3]$ | $[Cl_2]$ | $[PCl_5]$ |
|---|---|---|---|---|
| | (A) | decreases | decreases | increases |
| | (B) | decreases | increases | decreases |
| | (C) | increases | decreases | increases |
| ✔ | (D) | increases | increases | decreases |

13. Which pH value would best describe a substance that tastes sour?

✔ (A) 6.8
(B) 7.0
(C) 7.2
(D) 14.0

14. What is the conjugate base of $H_2PO_4^-(aq)$?

✔ (A) $HPO_4^{2-}(aq)$
(B) $H_3PO_4(aq)$
(C) $OH^-(aq)$
(D) $PO_4^{3-}(aq)$

15. Which substance is amphoteric?

(A) $CH_3COO^-(aq)$
(B) $CO_3^{2-}(aq)$
✔ (C) $HCO_3^-(aq)$
(D) $SO_3^{2-}(aq)$

16. Which is an acid-base conjugate pair?

$$HCO_3^-(aq) + HNO_2(aq) \rightleftharpoons H_2CO_3(aq) + NO_2^-(aq)$$

| | Acid | Conjugate Base |
|---|---|---|
| (A) | $HCO_3^-$ | $H_2CO_3$ |
| (B) | $HCO_3^-$ | $NO_2^-$ |
| (C) | $HNO_2$ | $H_2CO_3$ |
| ✔ (D) | $HNO_2$ | $NO_2^-$ |

17. Which best describes a 10.0 mol/L solution of hydrofluoric acid?

(A) strong and concentrated
(B) strong and dilute
✔ (C) weak and concentrated
(D) weak and dilute

18. The pH of a sample of rainwater has changed from 5.4 to 4.4. What is true of the rainwater?

| | $[H_3O^+]$ | Factor |
|---|---|---|
| (A) | decrease | 1 |
| (B) | decrease | 10 |
| (C) | increase | 1 |
| ✔ (D) | increase | 10 |

19. What is the pH of a 0.00946 mol/L solution of barium hydroxide, $Ba(OH)_2$?

(A) 1.723
(B) 2.024
(C) 11.976
✔ (D) 12.277

20. What is the pH of a solution made by diluting 10.0 mL of a 0.214 mol/L solution of nitric acid, $HNO_3(aq)$, to a volume of 200.0 mL?

(A) 0.670
✔ (B) 1.971
(C) 12.029
(D) 13.330

21. What is $[H_3O^+]$ of a solution with a pH of 2.00?

(A) 0.0010 mol/L
✔ (B) 0.010 mol/L
(C) 0.020 mol/L
(D) 2.0 mol/L

22. Which is representative of the weakest acid?

✔ (A) $K_a = 6.9 \times 10^{-8}$
(B) $K_a = 3.6 \times 10^{-6}$
(C) $K_a = 2.6 \times 10^{-4}$
(D) $K_a = 1.9 \times 10^{-2}$

23. Which acid would be expected to have the lowest $K_a$ value?

| | Volume (mL) | pH | Conductivity |
|---|---|---|---|
| (A) | 50.2 | 3.25 | poor |
| (B) | 40.5 | 3.25 | good |
| (C) | 20.7 | 5.50 | good |
| ✔ (D) | 15.0 | 5.50 | poor |

24. What is the $K_a$ of a weak acid, HA, if the pH at equilibrium for the acid is 2.20 and the equilibrium concentration of HA is 0.930 mol/L?

✔ (A) $4.3 \times 10^{-5}$
(B) $6.8 \times 10^{-3}$
(C) $1.5 \times 10^{2}$
(D) $2.3 \times 10^{4}$

25. The blood's natural buffering system ($H_2CO_3(aq)/HCO_3^-(aq)$) allows it to maintain a pH of 7.35. When a small amount of base enters the blood, with what species does it react?

(A) $H_3O^+(aq)$
(B) $HCO_3^-(aq)$
✔ (C) $H_2CO_3(aq)$
(D) $H_2O(\ell)$

26. A solution was tested with three indicators to give the results shown. What is the approximate pH of the solution?

| Indicator | Final Colour |
|---|---|
| bromocresol green | blue |
| indigo carmine | blue |
| thymolphthalein | blue |

(A) 5.00
(B) 9.00
✔ (C) 10.8
(D) 11.6

27. Which term describes the colour change when an acid-base indicator is used?

✔ (A) end point
(B) equilibrium point
(C) equivalence point
(D) neutralization point

28. If the $K_a$ expression for an acid is $K_a = \frac{[H_3O^+][NO_2^-]}{[HNO_2]}$, what is the $K_b$ expression for its conjugate base?

(A) $K_b = \frac{[HNO_2]}{[H_3O^+][NO_2^-]}$

(B) $K_b = \frac{[H_3O^+][HNO_2]}{[NO_2^-]}$

✔ (C) $K_b = \frac{[OH^-][HNO_2]}{[NO_2^-]}$

(D) $K_b = \frac{[OH^-][NO_2^-]}{[HNO_2]}$

29. What is a measure of the average kinetic energy of particles?

(A) heat capacity
(B) molar enthalpy
(C) specific heat
✔ (D) temperature

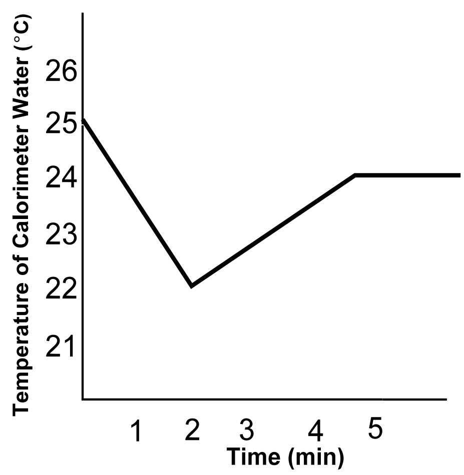
30. What is the molar enthalpy change for the reaction below?

$$MgCO_3(s) \rightarrow MgO(s) + CO_2(g)$$

| Chemical | $\Delta H^\circ_f$ (kJ/mol) |
|---|---|
| $MgCO_3(s)$ | −1113 |
| $MgO(s)$ | −602 |
| $CO_2(g)$ | −394 |

(A) −2109 kJ/mol
(B) −117 kJ/mol
✔ (C) 117 kJ/mol
(D) 2109 kJ/mol

31. A piece of ice was dropped into liquid water to determine the molar heat of fusion of water. What is the best interpretation of the results as shown in the graph below?




✔ (A) The ice finishes melting at 2 minutes and heat enters the container.
(B) The ice finishes melting at 2 minutes and heat leaves the container.
(C) The ice finishes melting at 5 minutes and heat enters the container.
(D) The ice finishes melting at 5 minutes and heat leaves the container.

32. If it takes 588 J of energy to change the temperature of a 28.7 g strip of copper from 26.3 °C to 79.5 °C, what is the specific heat capacity of copper?

(A) 0.258 J/g·°C
✔ (B) 0.385 J/g·°C
(C) 2.60 J/g·°C
(D) 20.5 J/g·°C

33. Which phase change is exothermic?

✔ (A) gas to liquid
(B) liquid to gas
(C) solid to gas
(D) solid to liquid

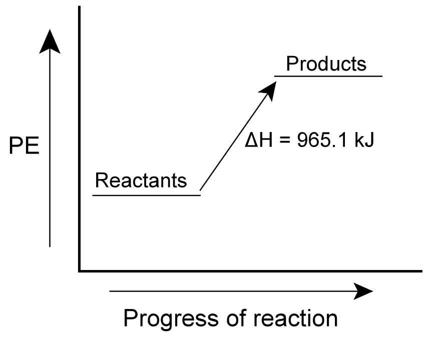
34. Which energy change occurs when water is heated from 37.0 °C to 95.0 °C?

(A) kinetic energy decreases
✔ (B) kinetic energy increases
(C) potential energy decreases
(D) potential energy increases

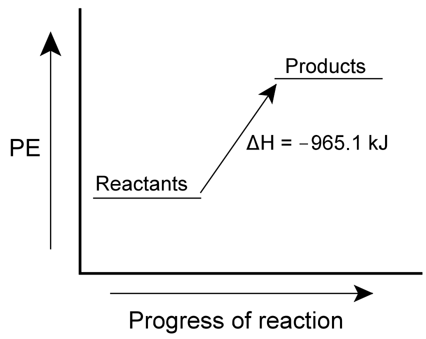
35. Which enthalpy diagram best represents the reaction below?

$$CH_4(g) + 2\,O_2(g) \rightarrow CO_2(g) + 2\,H_2O(\ell) + 965.1\text{ kJ}$$

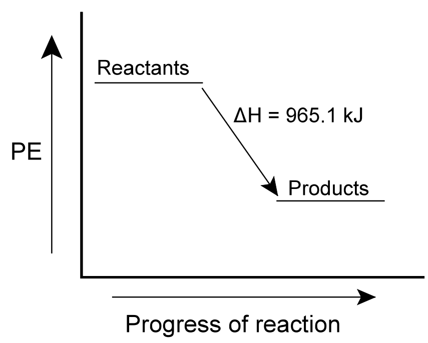
(A)



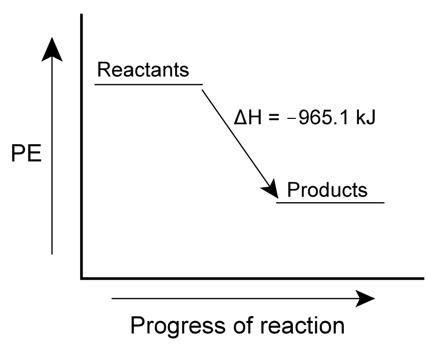

(B)




(C)




✔ (D)



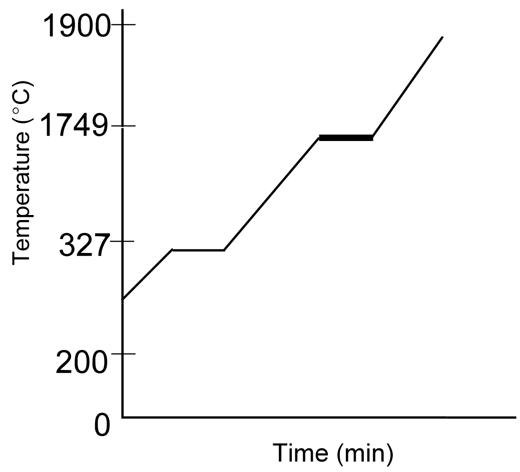

36. The molar heat of solution for NaOH(s) is −44.6 kJ/mol. What is true if a sample of NaOH(s) is dissolved in water in a calorimeter?

| | | Temperature of Water | Reaction |
|---|---|---|---|
| | (A) | decreases | absorbs energy |
| | (B) | decreases | releases energy |
| | (C) | increases | absorbs energy |
| ✔ | (D) | increases | releases energy |

37. Samples of two compounds X and Y have identical masses and initial temperatures. They are placed in an insulated container and a quantity of heat is added. What can be concluded if the final temperature of X is lower than that of Y?

(A) The molar mass of X is greater than that of Y.
(B) The molar mass of X is less than that of Y.
✔ (C) The specific heat capacity of X is greater than that of Y.
(D) The specific heat capacity of X is less than that of Y.

38. The graph below shows the heating curve of a substance. What is its melting point?




(A) 250 °C
✔ (B) 327 °C
(C) 1749 °C
(D) 1900 °C

39. A student walks to school in 0.50 hours travelling at 6 km/h. Before she leaves her house she eats 60.0 g of granola. How much energy will remain when she arrives at school? (FV of granola is 20.3 kJ/g; walking at 6 km/h burns 1675 kJ/h of energy.)

✔ (A) 380 kJ
(B) 460 kJ
(C) 840 kJ
(D) 1200 kJ

40. Given the reaction below, what is the molar enthalpy of formation for $NH_3(g)$?

$$N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g) + 92\text{ kJ}$$

(A) −92 kJ/mol
✔ (B) −46 kJ/mol
(C) 46 kJ/mol
(D) 92 kJ/mol

41. Which is a balanced oxidation half-reaction?

(A) $Br_2(\ell) + 2\ e^- \rightarrow 2\ Br^-(aq)$

(B) $2\ H^+ + 2\ e^- \rightarrow H_2(g)$

(C) $Sn^{2+}(aq) \rightarrow Sn(s) + 2\ e^-$

✔ (D) $Sn^{2+}(aq) \rightarrow Sn^{4+}(aq) + 2\ e^-$

42. Which species is the reducing agent in the reaction below?

$$5\,Fe^{2+}(aq) + MnO_4^-(aq) + 8\,H^+(aq) \rightarrow 5\,Fe^{3+}(aq) + Mn^{2+}(aq) + 4\,H_2O(\ell)$$

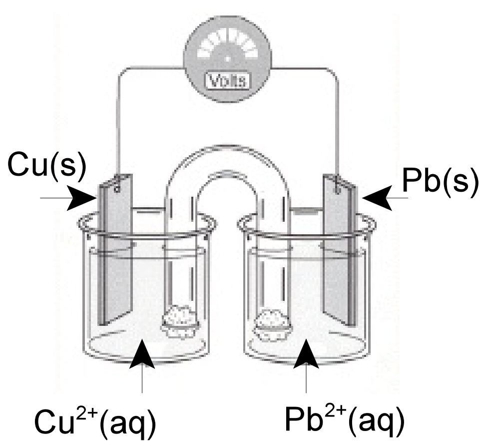
✔ (A) $Fe^{2+}(aq)$
(B) $Fe^{3+}(aq)$
(C) $Mn^{2+}(aq)$
(D) $MnO_4^-(aq)$

43. What is the balanced equation for the reaction below?

$$Co^{3+}(aq) + Cd(g) \rightarrow Co^{2+}(aq) + Cd^{2+}(aq)$$

(A) $Co^{3+}(aq) + Cd(g) \rightarrow Co^{2+}(aq) + Cd^{2+}(aq)$
(B) $Co^{3+}(aq) + 2\,Cd(g) \rightarrow Co^{2+}(aq) + 2\,Cd^{2+}(aq)$
✔ (C) $2\,Co^{3+}(aq) + Cd(g) \rightarrow 2\,Co^{2+}(aq) + Cd^{2+}(aq)$
(D) $2\,Co^{3+}(aq) + 2\,Cd(g) \rightarrow 2\,Co^{2+}(aq) + 2\,Cd^{2+}(aq)$

44. Which is the cathode in the diagram below?




✔ (A) Cu(s)
(B) $Cu^{2+}(aq)$
(C) Pb(s)
(D) $Pb^{2+}(aq)$

45. What is the overall cell potential for the cell in which the reaction below occurs?

$$Au^{3+}(aq) + 3\,NO_2(g) + 3\,H_2O(\ell) \rightarrow Au(s) + 3\,NO_3^-(aq) + 6\,H^+(aq)$$

(A) −0.90 V
(B) −0.70 V
✔ (C) 0.70 V
(D) 0.90 V

46. How many moles of electrons are transferred if a current of 1.80 A is allowed to run for 125 s?

(A) $3.89 \times 10^{-5}$ mol
✔ (B) $2.33 \times 10^{-3}$ mol
(C) $4.29 \times 10^{2}$ mol
(D) $1.39 \times 10^{3}$ mol

47. Which is the strongest reducing agent in the table below?

✓ indicates evidence of reaction
✗ indicates no evidence of reaction

| | W(s) | X(s) | Q(s) | Z(s) |
|---|---|---|---|---|
| $W^-$(s) | ✗ | ✓ | ✓ | ✗ |
| $X^{2-}$(s) | ✗ | ✗ | ✓ | ✗ |
| $Q^{2-}$(s) | ✗ | ✗ | ✗ | ✗ |
| $Z^{3-}$(s) | ✓ | ✓ | ✓ | ✗ |

(A) Q(s)
(B) $Q^-$(aq)
(C) Z(s)
✔ (D) $Z^{3-}$(aq)

48. Nickel (II) subsulfide, $Ni_3S_2$, is mined at Voisey's Bay. What is the oxidation number of S in $Ni_3S_2$?

✔ (A) −3
(B) −2
(C) −1
(D) 0

49. What type of cell is a rechargeable nickel-cadmium cell?

(A) fuel
(B) hydrogen
(C) primary
✔ (D) secondary

50. Which describes the energy conversion that occurs in an electrolytic cell?

(A) chemical to electrical
(B) chemical to mechanical
✔ (C) electrical to chemical
(D) electrical to mechanical

## 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 digits where appropriate.**

**Value**

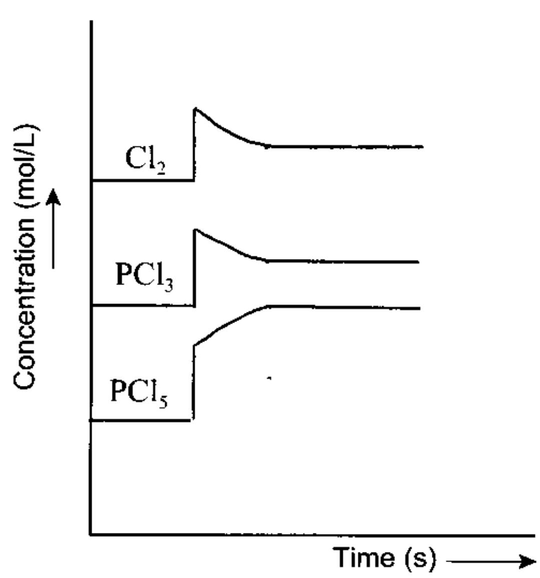
2% 51.(a) For the reaction shown, explain how increasing the temperature would increase the rate of production of $O_2(g)$.

$$6\,CO_2(g) \;+\; 6\,H_2O(\ell) \;\rightarrow\; C_6H_{12}O_6(s) \;+\; 6\,O_2(g)$$

**Increase in temperature causes reactant particles to move faster [½ mark] thus colliding more often [½ mark] and with more intensity [½ mark]. More collisions will excess the $E_a$ and have proper orientation [½ mark], thus the rate increases.**

3% (b) For the equilibrium reaction shown, sketch the change in concentration for each reactant and product as the volume of the container is decreased and the system re-establishes equilibrium.

$$PCl_5(g) \rightleftharpoons Cl_2(g) \;+\; PCl_3(g)$$




**[1.0 mark] for conc increase**
**[1.0 mark] for the change**
**[1.0 mark] for re-establish eqbm**

**Value**

3% 51.(c) Explain three changes that can be imposed on the system below that will allow the maximum amount of $C_6H_6$ to be produced.

$$3\ C_2H_2(g) \rightleftharpoons C_6H_6(\ell) + 633\ kJ$$

**Any three of the following four:**

**1) increase $[C_2H_2]$ - system shifts right to use it up producing $C_6H_6$**

**2) remove $C_6H_6$ as it forms - system shifts right to produce more of it**

**3) decrease temperature - system shifts right to produce energy thus producing $C_6H_6$**

**4) increase pressure/decrease volume - system shifts right to produce less gas molecules thus producing $C_6H_6$**

**[½ mark] x 3 for the change; [½ mark] x 3 for the explanation**

5% (d) If 2.00 mol of HCl(g) is placed in an evacuated 3.00 L container and the equilibrium below is established, calculate the equilibrium concentration of all reactants and products.

$$2\ HCl(aq) \rightleftharpoons H_2(g) + Cl_2(g) \qquad K = 3.4 \times 10^{-2}$$

$$c = \frac{n}{v} = \frac{2.00\ mol}{3.00\ L} = 0.667\ mol/L$$

| | | | |
|---|---|---|---|
| **I** | **0.667 mol/L** | **0** | **0** |
| **C** | **- 2*x*** | **+*x*** | **+*x*** |
| **E** | **0.667 - 2*x*** | ***x*** | ***x*** |

**[1.0 mark]**

$$K = \frac{[H_2]\ [Cl_2]}{[HCl]^2}$$ **[½ mark]**

$$0.034 = \frac{x^2}{(0.667 - 2x)^2}$$ **[½ mark]**

**taking square root of both sides is much quicker than solving the quadratic since the assumption will not work**

$$0.18(4) = \frac{x}{0.667 - 2x}$$ **[½ mark]**

$$0.12(3) - 0.36(8)\,x = x$$

$$x = 0.089(9)$$ **[½ mark]**

**thus** $[H_2] = [Cl_2] = x = 0.090\ mol/L$ **[½ mark]**

$[HCl] = 0.667 - 2x = 0.667 - (2 \times 0.089(9)) = 0.487\ mol/L$ **[½ mark]**

**[1.0 mark] for science communication**

Value

2% 52.(a) Use an appropriate acid-base theory to explain why an aqueous solution of lithium hydrogen sulfate ($LiHSO_4(aq)$) turns blue litmus red.

**$LiHSO_4 \rightarrow Li^+ + HSO_4^-$ blue litmus red $HSO_4^-$ is an acid**

**Either:**

**Modern Arrhenius: the $HSO_4^-$ reacts with water to form $H_3O^+$ ions**

$$HSO_4^- + H_2O \rightarrow H_3O^+ + SO_4^{2-}$$

**Or:**

**Bronsted-Lowry: the $HSO_4^-$ donates a proton**

$$HSO_4^- + H_2O \rightleftharpoons H_3O^+ + SO_4^{2-}$$

4% (b) What is the pH of the resulting solution prepared by mixing 25.00 mL of a 0.220 mol/L KOH(aq) solution with 30.00 mL of a 0.150 mol/L HCl(aq) solution?

**$HCl(aq) + KOH(aq) \rightarrow H_2O(l) + KCl(aq)$ (½ mark)**

**or $H_3O^+(aq) + OH^-(aq) \rightarrow 2\ H_2O(l)$**

**$n_{(HCl)} = c\ v = (0.150\ M)\ (0.03000\ L) = 4.50 \times 10^{-3}$ mol (1.0 mark)**

**$n_{(KOH)} = c\ v = (0.220\ M)\ (0.02500\ L) = 5.50 \times 10^{-3}$ mol**

**Ratio: HCl : KOH is 1 : 1**

**Excess $OH^-$ : $4.50 \times 10^{-3}$ mol of HCl reacts with $4.50 \times 10^{-3}$ mol of KOH leaving 0.00100 mol KOH (½ mark)**

**$c_{(KOH)} = \dfrac{0.00100\ mol}{0.0550\ L} = 0.0181(8)\ mol/L = [OH^-]$ (1.0 mark)**

**$pOH = -\log [OH^-] = -\log 0.0181(8) = 1.74$ (½ mark)**

**$pH = 14.000 - pOH = 14.000 - 1.74 = 12.26$ (½ mark)**

Value

4% 52.(c) A 0.10 mol/L acid HA(aq) has a $K_a$ value of $5.9 \times 10^{-6}$.

(i) What is the pH of the solution?

| | HA | $+ H_2O \rightleftharpoons$ | $H_3O^+$ | $A^-$ |
|---|---|---|---|---|
| **I** | **0.10** | | **0** | **0** |
| **C** | **$-x$** | | **$+x$** | **$+x$** |
| **E** | **$0.10 - x$** | | **$+x$** | **$+x$** |

**check** $\frac{[HOCl]_i}{K_a} = \frac{0.10}{5.9 \times 10^{-6}} > 500$ **assume good** **(½ mark)**

**thus assume** $0.10 - x \sim 0.10$ **(½ mark)**

$K_a = \frac{[H_3O^+][A^-]}{[HA]}$ **(½ mark)**

$5.9 \times 10^{-6} = \frac{x^2}{0.10}$ **(½ mark)**

$x = 7.6(8) \times 10^{-4} = [H_3O^+]$ **(½ mark)**

$pH = -\log [H_3O^+] = -\log 7.6(8) \times 10^{-4} = 3.11$ **(½ mark)**

(ii) Calculate the percent ionization of the acid.

$\%\ rxn = \frac{[\ ]_{change}}{[\ ]_{initial}} \times 100\% = \frac{7.6(8) \times 10^{-4}}{0.10} \times 100\% = 0.77\ \%$

[**1.0 mark**]

4% (d) A pipette is used to transfer four 25.00 mL samples of hydrochloric acid, HCl(aq), to flasks. Each sample is then titrated to the equivalence point using a solution prepared by dissolving 0.200 g of sodium carbonate, $Na_2CO_3$, to form 100.0 mL of solution. The results below were obtained. What is the concentration of HCl(aq)?

| Trial | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Final burette reading (mL) | 20.98 | 33.26 | 33.12 | 45.43 |
| Initial burette reading (mL) | 8.08 | 20.98 | 20.83 | 33.12 |
| Volume of $Na_2CO_3$ added (mL) | 12.90 | 12.28 | 12.29 | 12.31 |

$$2\,HCl(aq) + Na_2CO_3(s) \rightarrow H_2O(\ell) + CO_2(g) + 2\,NaCl(aq)$$

**Avg Volume used = (12.28 + 12.29 + 12.31) mL / 3 = 12.29(3) mL** **(½ mark)**

$n(Na_2CO_3) = \frac{m}{M} = \frac{0.200\ g}{105.99\ g/mol} = 0.00188(7)\ mol$ **(1.0 mark)**

$c(Na_2CO_3) = \frac{n}{v} = \frac{0.00188(7)\ mol}{0.1000\ L} = 0.0188(7)\ mol/L$ **(½ mark)**

$n_{used}(Na_2CO_3) = c \times v = (0.0188(7)\ mol/L)(0.01229(3)\ L) = 2.32 \times 10^{-4}\ mol$ **(½ mark)**

$n(HCl) = 2.32 \times 10^{-4}\ mol\ Na_2CO_3 \times \frac{2\ mol\ HCl}{1\ mol\ Na_2CO_3} = 4.63(9) \times 10^{-4}\ mol$ **(1.0 mark)**

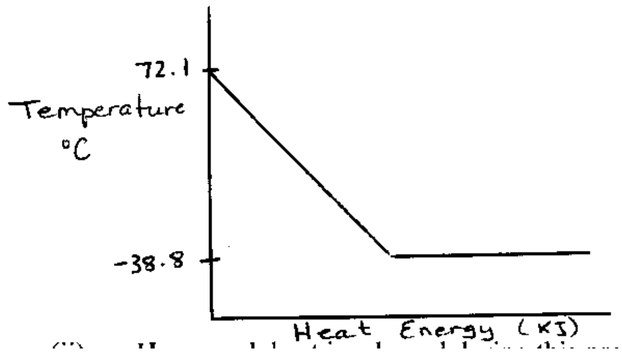
$c(HCl) = \frac{n}{v} = \frac{4.63(9) \times 10^{-4}\ mol}{0.02500\ L} = 0.0186\ mol/L$ **(½ mark)**

Value

4% 53.(a) A 2.71 g sample of mercury at 72.1 °C is cooled to −38.8 °C and solidified.

(i) Draw a cooling curve for this process.

| | |
|---|---|
| melting point Hg | −38.8 °C |
| specific heat | 0.140 J/g·°C |
| $\Delta H_{fusion}$ | 8.9 kJ/mol |




**[1.0 mark]**

(ii) How much heat is released during this process?

**$q_1$ = mc$\Delta$T = (2.71 g) (0.140 J/g•°C) (-38.8°C - 72.1°C) = - 42.0(8) J [1.0 mark]**

**$q_2 = n\Delta H_{sol} = \dfrac{2.71\text{ g}}{200.59\text{ g/mol}}$ x - 8.9 kJ/mol = - 0.12 kJ [1.0 mark]**

**$\Delta E_T$ = - 0.0420(8) kJ + - 0.12 kJ = - 0.16 kJ or 1.6 x $10^2$ J [1.0 mark]**

5% (b) 50.0 mL of 0.500 mol/L HCl(aq) is mixed with 50.0 mL of 0.500 mol/L NaOH(aq) in a coffee cup calorimeter. The initial temperature of each solution is 18.2 °C and the highest recorded temperature is 23.2 °C.

$$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(\ell)$$

(i) Calculate the enthalpy of neutralization of HCl.

**$m_{aq\ soln}$ = 50.0 g + 50.0 g = 100.0 g Assume $D_{aq\ soln} = D_{water}$ = 1.00 g/mL**
**[½ mark]**

**$q_{rxn} = - q_{aq\ soln}$ [½ mark]**
**= - (100.0 g) (4.184 J/g•°C) (23.2°C - 18.2°C)**
**= - 20(92)J**
**= - 2.0(9) kJ [1.0 mark]**

**$n_{HCl} = n_{NaOH}$ ratio 1:1 thus all HCl completely reacts**

**$n_{HCl}$ = c x v = (0.500 mol/L) (0.0500L) = 0.0250 mol [½ mark]**

**$\Delta H_{neutralized\ HCl} = \dfrac{q}{n} = \dfrac{-2.0(9)\text{ kJ}}{0.0250\text{ mol}}$ = - 84 kJ [½ mark]**

**[1.0 mark] for science communication**

(ii) State two assumptions that must be made in this case in determining the enthalpy of neutralization.

| **Any 2 of the following 4:** | **[½ mark @]** |
|---|---|
| **1)** | **$q_{calorimeter} = 0$** |
| **2)** | **$D_{aq\ soln} = D_{water}$** |
| **3)** | **$c_{aq\ soln} = c_{water}$** |
| **4)** | **$q_{outside\ surroundings} = 0$ (system is isolated)** |

Value

4% 53.(c). Using the data below, calculate the enthalpy of formation for $Bi_2O_3(s)$.

$$BiCl_3(s) + Bi_2O_3(s) \rightarrow 3\,BiOCl(s) \quad \Delta H = -147.7 \text{ kJ}$$

$$Bi(s) + \tfrac{3}{2}Cl_2(g) \rightarrow BiCl_3(s) \quad \Delta H_f = -379.1 \text{ kJ} \quad ]\ x\ {-1}$$

$$2\,Bi(s) + \tfrac{3}{2}O_2(g) \rightarrow Bi_2O_3(s) \quad \Delta H_f = ? \quad ]\ x\ {-1}$$

$$Bi(s) + \tfrac{1}{2}O_2(g) + \tfrac{1}{2}Cl_2(g) \rightarrow BiOCl(s) \quad \Delta H_f = -366.9 \text{ kJ} \quad ]\ x\ 3$$

**$BiCl_3(s) \rightarrow Bi(s) + \tfrac{3}{2}Cl_2(g)$ $\Delta H = +379.1$ kJ [1 mark]**

**$Bi_2O_3(s) \rightarrow 2\,Bi(s) + \tfrac{3}{2}O_2(g)$ $\Delta H =$ ? x -1 [1 mark]**

**$3\,Bi(s) + 3/2\,O_2(g) + 3/2\,Cl_2(g) \rightarrow 3\,BiOCl(s)$ $\Delta H = -1100.7$ kJ [1 mark]**

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**$BiCl_3(s) + Bi_2O_3(s) \rightarrow 3\,BiOCl(s)$ $\Delta H_{rxn} = -147.7$ kJ**

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**Thus**

**$379.1 \text{ kJ} + -\Delta H + (-1100.7 \text{ kJ}) = -147.7 \text{ kJ}$**

**$-\Delta H = -147.7 \text{ kJ} + (-379.1 \text{ kJ}) + 1100.7 \text{ kJ}$**

**$-\Delta H = 573.9 \text{ kJ}$**

**$\Delta H_f = -573.9 \text{ kJ}$ [1 mark]**

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

$$Ag^+(aq) + S_2O_3^{2-}(aq) \rightarrow SO_4^{2-}(aq) + Ag(s)$$

**$5\,H_2O + S_2O_3^{2-} \rightarrow 2\,SO_4^{2-} + 10\,H^+ + 8\,e^-$ [1 mark]**
**$Ag^+ + e^- \rightarrow Ag$ ] x 8 [½ mark]**

---

**$5\,H_2O + S_2O_3^{2-} \rightarrow 2\,SO_4^{2-} + 10\,H^+ + 8\,e^-$**
**$8\,Ag^+ + 8\,e^- \rightarrow 8\,Ag$ [½ mark]**

---

**$5\,H_2O + S_2O_3^{2-} + 8\,Ag^+ \rightarrow 2\,SO_4^{2-} + 10\,H^+ + 8\,Ag$ [1 mark]**

Value

4% 54.(b) In an electrolytic cell, 0.061 g of Zn(s) was plated in 10.0 minutes from a solution of $ZnCl_2(aq)$. What current was used?

**Plating at the cathode:** $Zn^{2+} + 2\ e^- \rightarrow Zn$ **[½ mark]**

$$n(Zn) = \frac{m}{M} = \frac{0.061\ g}{65.38\ g/mol} = 9.3(3) \times 10^{-4}\ mol$$ **[½ mark]**

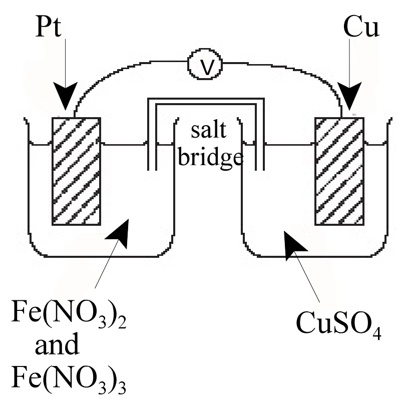
$$n(e^-) = 9.3(3) \times 10^{-4}\ mol\ Zn \times \frac{2\ mol\ e^-}{1\ mol\ Zn} = 0.0018(7)\ mol$$ **[½ mark]**

$$Q = n_{e-} \times F = (0.0018(7)\ mol)(96500\ C/\ mol\ e^-) = 180\ C$$ **[½ mark]**

$$I = \frac{Q}{t} = \frac{180\ C}{10.0\ min \times \frac{60\ s}{1\ min}} = 0.30\ A$$ **[1.0 mark]**

**[1.0 mark] for science communication**

3% (c) A student constructed an electrochemical cell as shown. The aqueous cell solutions had a concentration of 1 mol/L with respect to the metal ions present. The solution in one half-cell is initially an orange colour due to the mixture of the pale green $Fe^{2+}$ ions and the orange $Fe^{3+}$ ions. The other half is coloured blue due to the $Cu^{2+}$ ions. Describe the colour changes the student would see in each half of the cell if the reaction proceeded until no further change took place.




**$Fe^{3+} + e^- \rightarrow Fe^{2+}$ $E° = + 0.77\ V$**

**$Cu^{2+} + 2\ e^- \rightarrow Cu$ $E° = + 0.34\ V$ this will become the oxidation at the anode**

**[1.0 mark]**

**Negative ions flow from cathode solution towards the anode solution.**

**Positive ions (blue $Cu^{2+}$) flow from anode solution towards cathode solution.**

**[1.0 mark]**

**Orange solution will become orange-blue color as $Cu^{2+}$ ions migrate in.**

**Blue solution will become a paler blue as $Cu^{2+}$ ions leave**

**[1.0 mark]**