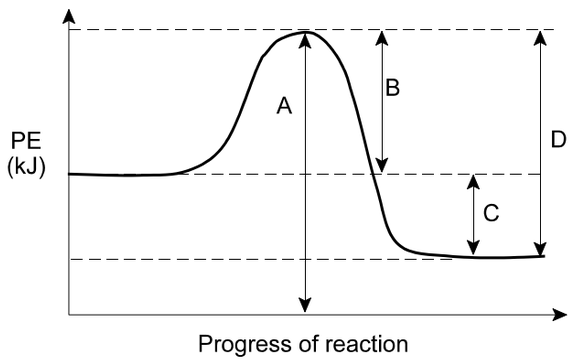
PART I
Total Value: 50%

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

1. Why does increasing temperature increase reaction rate?

   (A) decreases activation energy
   (B) decreases the percentage of effective collisions
   (C) increases activation energy
   (D) increases the percentage of effective collisions

2. Which represents the activation energy for the forward reaction in the diagram below?



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

3. Which type of change is best for monitoring the reaction rate of the reaction below?

$$Mg(OH)_2(s) + 2\,HCl(aq) \rightarrow 2\,H_2O(\ell) + MgCl_2(aq)$$

   (A) colour
   (B) mass
   (C) pH
   (D) volume

4. Which describes an activated complex?

   (A) has a lower potential energy than products
   (B) has a lower potential energy than reactants
   (C) stable species that forms upon collision of reactants
   (D) unstable species that forms upon collision of reactants

5. According to the collision theory, why does the reaction below occur in more than one step?

$$C_5H_{12}(g) + 8\,O_2(g) \rightarrow 5\,CO_2(g) + 6\,H_2O(g)$$

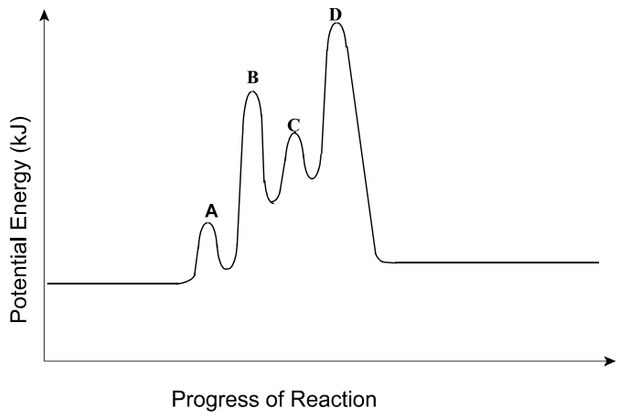
   (A) low $C_5H_{12}(g)$ concentration
   (B) low probability of a nine-particle collision
   (C) particles collide with insufficient kinetic energy
   (D) temperature is very high

6. What is the catalyst in the reaction mechanism below?

$$\tfrac{1}{2}\,O_2 + NO(g) \rightarrow NO_2(g)$$
$$NO_2(g) \rightarrow NO(g) + O(g)$$
$$O(g) + O_2(g) \rightarrow O_3(g)$$
$$\tfrac{3}{2}\,O_2(g) \rightarrow O_3(g)$$

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

7. For the reaction represented below, which is the rate determining step for the reverse reaction?



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

8. Which has the least effect on the equilibrium below?

$$H_2(g) + Br_2(g) \rightleftarrows 2\,HBr(g)$$

(A) adding more reactant
(B) adding more product
(C) decreasing temperature
(D) decreasing volume

9. When $H_2(g)$ was added to the equilibrium below, how will the forward and reverse reaction rates change following the establishment of a new equilibrium?

$$H_2(g) + I_2(g) \rightleftarrows 2HI(g)$$

	Forward	Reverse
(A)	decrease	decrease
(B)	decrease	increase
(C)	increase	decrease
(D)	increase	increase

10. Which Keq value best represents an equilibrium in which the formation of products is favored?

(A) 7.3×10^{-18}
(B) 4.2×10^{-4}
(C) 1.0
(D) 85

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

$$Fe_2O_3(s) + 3\,CO(g) \rightleftarrows 2\,Fe(s) + 3\,CO_2(g)$$

(A) $\dfrac{[CO_2]^3}{[CO]^3}$

(B) $\dfrac{[CO]^3}{[CO_2]}$

(C) $\dfrac{[CO_2]^3[Fe]^2}{[Fe_2O_3][CO]^3}$

(D) $\dfrac{[Fe_2O_3][CO]^3}{[CO_2]^3[Fe]^2}$

12. What is [HCl(g)] in the equilibrium below, if [H_2(g)] and [Cl_2(g)] are both 0.250 mol/L?

$$H_2(g) + Cl_2(g) \rightleftarrows 2\,HCl(g) \qquad K = 0.275$$

(A) 0.0172 mol/L
(B) 0.131 mol/L
(C) 0.227 mol/L
(D) 4.40 mol/L

13. Which best describes a solution with pH = 3?

(A) litmus turns blue
(B) litmus turns red
(C) phenol red turns red
(D) phenol red turns pink

14. According to Bronsted-Lowry theory, what is an acid?

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

15. Which ion is amphoteric?

(A) Cl^-
(B) HSO_3^-
(C) O^{2-}
(D) NH_4^+

16. Which is a conjugate acid-base pair in the equilibrium below?

$$HCN(aq) + CH_3NH_2(aq) \rightleftarrows CN^-(aq) + CH_3NH_3^+(aq)$$

(A) CH_3NH_2 and CN^-
(B) CN^- and $CH_3NH_3^+$
(C) HCN and CH_3NH_2
(D) HCN and CN^-

17. Which describes the relative strengths of the acids and bases in the equilibrium below if reactants are favoured?

$$HIO_3 + F^- \rightleftarrows IO_3^- + HF$$

	Stronger Acid	Stronger Base
(A)	HF	F^-
(B)	HF	IO_3^-
(C)	HIO_3	F^-
(D)	HIO_3	IO_3^-

18. What is the net ionic equation for the reaction between methanoic acid, HCOOH(aq), with potassium hydroxide, KOH(aq)?

(A) $HCOOH(aq) + K^+(aq) + OH^-(aq) \rightleftarrows H_2O(\ell) + K^+(aq) + HCOO^-(aq)$

(B) $HCOOH(aq) + KOH(aq) \rightleftarrows H_2O(\ell) + KHCOO(aq)$

(C) $HCOOH(aq) + OH^-(aq) \rightleftarrows H_2O(\ell) + HCOO^-(aq)$

(D) $H_3O^+(aq) + OH^-(aq) \rightleftarrows 2H_2O(\ell)$

19. What is the nature of the acid-base reaction between $NH_4^+(aq)$ and $CN^-(aq)$?

	Species Favored	Reaction Arrows
(A)	products	$\rightleftarrows$
(B)	products	$\rightarrow$
(C)	reactants	$\rightleftarrows$
(D)	reactants	$\rightarrow$

20. What is $[H_3O^+]$ for pure water at 25 ºC?

(A) 1.0×10^{-14}
(B) 1.0×10^{-7}
(C) 1.0×10^{7}
(D) 1.0×10^{14}

21. What is the pH of a solution if $[H_3O^+]$ is 0.0001 mol/L?

(A) 1.0
(B) 4.0
(C) 10.0
(D) 14.0

22. An acid solution with pH = 1.0 is diluted. Which best describes what happens to $[H_3O^+(aq)]$ and $[OH^-(aq)]$?

	$[H_3O^+(aq)]$	$[OH^-(aq)]$
(A)	decreases	decreases
(B)	decreases	increases
(C)	increases	decreases
(D)	increases	increases

23. Which best explains why a 0.10 mol/L $CH_3COOH(aq)$ has a lower pH than a 1.0×10^{-6} mol/L HCl(aq)?

(A) acid strength
(B) concentration of solution
(C) surface area
(D) volume of solution

24. Hydrangea are flowers that display different colours under different soil pH. They are blue when the pH is less than 5.5, and pink when the pH is greater than 6.0. Which should be added to the soil to change the flowers from blue to pink?

(A) CH_3COOH
(B) HCOOH
(C) $MgCO_3$
(D) NH_4NO_3

25. Which is an Arrhenius base?

(A) HCl
(B) CH_3OH
(C) KOH
(D) Na_2CO_3

26. What volume of 0.500 M NaOH is required to neutralize 25.0 mL of 0.250 mol/L HBr?

(A) 5.00 mL
(B) 12.5 mL
(C) 20.0 mL
(D) 25.0 mL

27. Which could be used to neutralize spilled acid?

(A) $CH_3COOH(aq)$
(B) $HCl(aq)$
(C) $H_2SO_4(aq)$
(D) $NaOH(aq)$

28. Which is a monoprotic acid?

(A) $HCOOH(aq)$
(B) $H_2CO_3(aq)$
(C) $H_3BO_3(aq)$
(D) $NaOH(aq)$

29. Which energy change occurs in water when it is heated from 25.0 °C to 50.0 °C?

(A) KE decreases
(B) KE increases
(C) PE decreases
(D) PE increases

30. A chemical reaction occurs in a coffee-cup without a lid. Which type of system is this?

(A) closed
(B) isolated
(C) open
(D) thermochemical

31. If a 1.50×10^3 g aluminum pot has a heat capacity of 1330 J/°C, what is the specific heat capacity of aluminum?

(A) 0.887 J/g°C
(B) 2.01 J/g°C
(C) 23.9 J/g°C
(D) 54.2 J/g°C

32. Which best describes the chemical and phase changes that occur in a burning candle?

	Chemical Change	Phase Change
(A)	endothermic	endothermic
(B)	endothermic	exothermic
(C)	exothermic	endothermic
(D)	exothermic	exothermic

33. Which symbol represents the molar heat for the reaction below?

$$2\ C_3H_6(g) + 9\ O_2(g) \rightarrow 6\ CO_2(g) + 6\ H_2O(g)$$

(A) ΔH_{comb}
(B) ΔH_{fus}
(C) ΔH_{soln}
(D) ΔH_{vap}

34. How much energy is needed to vaporize 3.00 mol of water at 100ºC?

(A) 12.1 kJ
(B) 13.6 kJ
(C) 18.1 kJ
(D) 122 kJ

35. According to the equilibrium below, what is the heat of reaction for the formation of one mole of HCl(aq)?

$$6\ HCl(aq) + Fe_2O_3(aq) \rightleftarrows 2\ FeCl_3(s) + 3\ H_2O(\ell) \qquad \Delta H = -300.0\ kJ$$

(A) -300.0 kJ
(B) -50.0 kJ
(C) 50.0 kJ
(D) 300.0 kJ

36. What is the energy required to raise the temperature of 1.0 g of a substance by 1.0 ºC?

(A) fuel value
(B) heat capacity
(C) one joule
(D) specific heat capacity

37. If the heat of fusion of a substance is 20.0 kJ/mol, what energy change occurs when 5.00 mol of liquid freezes at its melting point?

(A) -100.0 kJ
(B) -20.0 kJ
(C) 20.0 kJ
(D) 100.0 kJ

38. Given the information for acetone below, which order of changes occurs when acetone is cooled from 45.0 ºC to -98.0 ºC?

Freezing Point	-95.4 ºC

Boiling Point	56.2 ºC

(A) phase- temperature- phase
(B) phase - temperature - phase - temperature
(C) temperature - phase - temperature
(D) temperature - phase - temperature - phase

39. Which best explains why burning $H_2(g)$ to form water releases approximately seven times the amount of energy released in condensing steam to form water?

(A) Burning $H_2(g)$ is a chemical reaction.
(B) Burning $H_2(g)$ is a nuclear change.
(C) Condensing steam is a chemical reaction.
(D) Condensing steam is a nuclear change.

40. Using the reactions below, determine the heat of reaction for the overall reaction?

Overall reaction: $2\ NO(g) + O_2(g) \rightarrow N_2O_4(g)$

$N_2O_4(g) \rightarrow 2\ NO_2(g) \qquad \Delta H = +57.9\ kJ$

$2\ NO(g) + O_2(g) \rightarrow 2\ NO_2(g) \qquad \Delta H = -113.1\ kJ$

(A) -171.0 kJ
(B) -55.2 kJ
(C) 55.2 kJ
(D) 171.0 kJ

41. Which involves atoms gaining electrons only?

(A) increase in oxidation number
(B) increase in reduction number
(C) oxidation
(D) reduction

42. Which is a redox reaction?

(A) $BaCl_2(aq) + Na_2SO_4(aq) \rightarrow BaSO_4(aq) + 2\ NaCl(aq)$

(B) $Cu(s) + 2\ AgNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2\ Ag(s)$

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

(D) $Mg^{2+}(aq) + CO_3^{2-}(aq) \rightarrow MgCO_3(s)$

43. What is the oxidation number of carbon in CO_3^{2-}?

(A) -4
(B) -2
(C) +2
(D) +4

44. Which is reduced in the reaction below?

$$2\ Sn^{2+}(aq) + 2\ O^{2-}(aq) \rightarrow 2\ Sn(s) + O_2(g)$$

(A) $O_2(g)$
(B) $O^{2-}(aq)$
(C) Sn(s)
(D) $Sn^{2+}(aq)$

45. Which is the strongest oxidizing agent?

(A) Au(s)
(B) $Cl_2(g)$
(C) $I_2(s)$
(D) Li(s)

46. Which half reaction is balanced for both atoms and charge?

(A) $ClO^- + 3\,H^+ + 3e^- \rightarrow Cl_2 + H_2O$

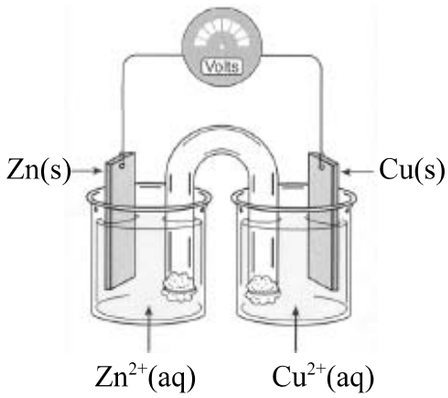
(B) $NO_2 + H_2O + 2e^- \rightarrow NO_3^- + 2\,H^+$

(C) $MnO_4^- + 8\,H^+ + 5e^- \rightarrow Mn^{2+} + 4\,H_2O$

(D) $SO_4^{2-} + 8\,H^+ + 6e^- \rightarrow H_2S + 4\,H_2O$

47. What is the cathode in the galvanic cell below?

$$Zn(s) + Cu^{2+}(aq) \rightarrow Cu(s) + Zn^{2+}(aq)$$



(A) Cu
(B) Cu^{2+}
(C) Zn
(D) Zn^{2+}

48. Which reactants will produce a spontaneous redox reaction?

(A) $Au(s) + Cu^{2+}(aq)$
(B) $Ca^{2+}(aq) + Zn(s)$
(C) $Co^{2+}(aq) + Al(s)$
(D) $Na(s) + Zn^{2+}(aq)$

49. What is the E^o value for the reduction of $Y^{3+}(aq)$ in the reaction below?

$$2\,Y^{3+}(aq) + 3\,Mg(s) \rightarrow 3\,Y(s) + 2\,Mg^{2+}(aq) \quad E^o = +4.03$$

(A) -2.37
(B) -1.66
(C) +1.66
(D) +2.37

50. Which is an example of a primary battery?

(A) alkaline
(B) lead storage
(C) nickel-cadmium
(D) rechargeable

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) The activation energy for the equilibrium below is 85.0 kJ.

$$I_2(g) + Cl_2(g) \rightleftarrows 2\ ICl(g) \qquad \Delta H = +\ 35.0\ kJ$$

(i) Sketch a clearly labelled potential energy diagram for this reaction, showing all energy terms for the forward and reverse reactions.

(ii) Illustrate the effect of adding a catalyst on the same diagram.

5% (b) When 3.00 mol of ammonia gas is placed in a 2.00 L flask, the equilibrium below is established.

$$2\ NH_3(g) \rightleftarrows N_2(g) + 3\ H_2(g)$$

At equilibrium, 0.600 mol of $H_2(g)$ is present. Calculate the value of Keq for this equilibrium.

Value

4% 51.(c) When a few drops of 6.0 M NaOH is added to 25.0 mL of the system below, a precipitate of $Fe(OH)_3(s)$ forms and the solution turns pale yellow.

$$Fe^{3+}(aq) + SCN^{-}(aq) \rightleftarrows FeSCN^{2+}(aq)$$
yellow *colourless* *red*

(i) Explain the colour change in terms of Le Châtelier's Principle.

(ii) Describe the effect on the rate of the reverse reaction as the colour change occurs?

4% 52.(a) $HPO_4^{2-}(aq)$ is an amphoteric substance.

(i) Write equations showing how $HPO_4^{2-}(aq)$ can act as both an acid and a base.

(ii) Identify the conjugate acid-base pairs in each equation.

as an acid:

as a base:

3% (b) What is the pH of a solution created by mixing 15.0 mL of 0.50 M HC1(aq) with 35.0 mL of 1.0 M NaOH(aq)?

Value

3% 52.(c) Acid dissociation constants for three weak acids are given below.

Acid	K_a (mol/L)
HX(aq)	2.3×10^{-4}
HY(aq)	7.1×10^{-5}
HZ(aq)	5.2×10^{-4}

(i) Arrange these acids in order of decreasing acid strength.

_____ → _____ → _____

most acidic least acidic

(ii) Excess Zn(s) is added to 100.0 mL samples of 0.10 M solutions of each acid. Which reaction would produce 100.0 mL of $H_2(g)$ fastest? Explain.

_____

_____

_____

_____

4% (d) The table below shows three distinct colour changes observed by three different indicators during the titration of 25.0 mL of $H_3BO_3(aq)$ with 0.10 M NaOH(aq).

Indicator	Colour Change
indigo carmine	blue → yellow
phenol red	yellow → red
thymolphthalein	colourless → blue

(i) Write the balanced equation for the reaction that occurs when the thymolphthalein changes colour.

(ii) If the colour change associated with thymolphthalein occurred when 60.0 mL of NaOH(aq) was added, calculate $[H_3BO_3(aq)]$.

Value

3% 53.(a) An aluminum ball is heated to 100.0°C and then placed in 75.0 mL of water at 20.0 °C in a coffee cup calorimeter. If thermal equilibrium is reached at 25.0 °C, c_{Al} = 0.900 J/g°C and c_{water} = 4.184 J/g°C, calculate the mass of the aluminum ball.

3% (b) Given the information below, estimate the energy released by the combustion of one mole of propane?

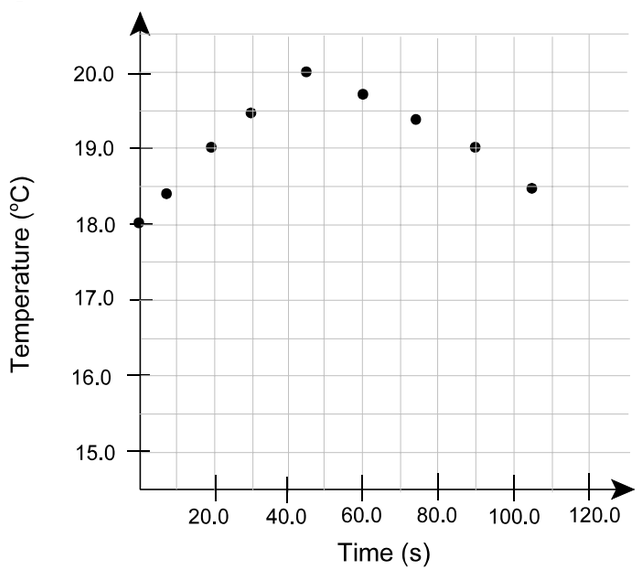
$$C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(\ell)$$

Bond	Average Bond Energy (kJ)
C – H	414
O = O	498
C – C	346
C = O	804
H – O	463

Value

3% 53.(c) Describe, using a labelled graph, the types of energy changes associated with the warming of a 20.0 kg block of ice at -10.0 ºC to liquid water at 20.0 ºC.

4% (d) A 2.0 g peanut is placed under a 15.0 g aluminum can (c_{Al} = 0.900 J/g·ºC) filled with 125.0 mL of water (c_{water} = 4.184 J/g·ºC) and ignited. The temperature of the water and can is recorded over time on the graph below. Calculate the fuel value of the peanut.



Value

4% 54.(a) Aluminum can be produced by the electrolysis of molten aluminum chloride, $AlCl_3$. If a 5.00 A current is passed through for 1.50 h, what mass of aluminum will be produced?

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

$$Pb(s) + NO_3^-(aq) \rightarrow Pb^{2+}(aq) + NO_2(g)$$

Value

3% 54.(d) The diagram below shows a Zn/Zn^{2+} half cell connected to another half cell of unknown composition. Identify the unknown half reaction. Justify your answer.