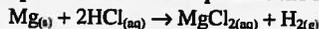


Multiple Choice Identify the letter of the choice that best completes the statement or answers the question. (20 marks)

1. What is the symbol for the enthalpy change that occurs during the phase change of a substance from solid to liquid?  
 a.  $\Delta H^{\circ}_{\text{vap}}$     b.  $\Delta H^{\circ}_{\text{cond}}$     **c.  $\Delta H^{\circ}_{\text{melt}}$**     d.  $\Delta H^{\circ}_{\text{frz}}$     e.  $\Delta H^{\circ}_{\text{boil}}$
2. A 20.0 g sample of aluminum is cooled 7.5°C. The specific heat capacity of aluminum is 0.900 J/g°C. What is the energy change for this sample?  
 a. 140 kJ    b. 140 J    c. -140 kJ    **d. -140 J**  
 $Q = mc\Delta T$   
 $= (20.0\text{g})(0.900\text{J/g}^{\circ}\text{C})(-7.5^{\circ}\text{C})$   
 $= -135\text{J}$   
 $= -0.135\text{kJ}$
3. 150.0 mL of water absorbs 7.84 kJ of energy. The specific heat capacity of water is 4.184 J/g°C. What is the temperature change?  
 a. 0.0125°C    **b. 12.5°C**    c. 353 K    d. 80°C    e. 80 K  
 $Q = mc\Delta T$   
 $\Delta T = \frac{Q}{mc}$   
 $m = \frac{V}{\rho} = (1.0\text{g/ml})(150\text{ml}) = 150\text{g}$   
 $\Delta T = \frac{7840\text{J}}{(4.184\text{J/g}^{\circ}\text{C})(150\text{g})} = 12.5^{\circ}\text{C}$
4. When a sample of potassium nitrate is dissolved in water, the temperature of the water changes from 23.5°C to 20.3°C. Which statement describes this process?  
 a. This process is exothermic, so the surroundings get cooler.  
 b. This process is exothermic, so the surroundings get warmer.  
**c. This process is endothermic, so the surroundings get cooler.**  
 d. This process is endothermic, so the surroundings get warmer.  
 e. None of the above options can be known for sure.
5. What is the definition of the temperature of a substance?  
 a. the total heat content of a substance  
 b. the speed of the fastest particles in the substance  
 c. the speed of the slowest particles in the substance, subtracted from the speed of the fastest particles in the substance  
 d. the heat capacity of the substance times its mass  
**e. the average kinetic energy of a system**
6. What is the definition of the specific heat capacity of a substance?  
**a. the amount of heat required to raise the temperature of 1 g of a substance 1°C**  
 b. the amount of heat required to raise the temperature of 1 mol of substance 1°C  
 c. the amount of heat required to raise the temperature of a substance 1°C  
 d. the amount of heat required to raise the temperature of 1 kg of a substance 1°C  
 e. the amount of heat required to raise the temperature of 1 g of a substance 100°C
7. Which statement describes an exothermic reaction?  
 a. The energy absorbed in bond breaking is more than the energy released in bond formation.  
**b. The energy absorbed in bond breaking is less than the energy released in bond formation.**  
 c. The system absorbs energy.  
 d. The surroundings cool down.  
 e. The potential energy of the reactants is less than the potential energy of the products.
8. In an exothermic reaction,  $\Delta H^{\circ}_{\text{rxn}}$  is . . .  
 a. always positive    **b. always negative**    c. negative or positive    d. zero    e. not possible to measure
9. The SI unit for energy is the joule (J). What is a joule in base units?  
 a.  $\text{kgm}^{-1}\text{s}^{-1}$     b.  $\text{kgm}^{-2}\text{s}^{-1}$     c.  $\text{kgm}^{-1}\text{s}^{-2}$     **d.  $\text{kgm}^{-2}\text{s}^{-2}$**     e.  $\text{kgm}^{-2}\text{s}^{-3}$
10. Which statement does not describe an endothermic reaction?  
 a. The surroundings cool down.  
 b.  $\Delta H^{\circ}_{\text{rxn}}$  is positive.  
**c. Heat is released by the system.**  
 d. Heat is absorbed by the system.  
 e. The potential energy of the products is greater than the potential energy of the reactants.
11. Which statement about the instantaneous rate of a reaction is not correct?  
 a. The higher the rate, the greater is the slope of a line on a concentration-time graph.  
 b. The instantaneous rate is the slope of the tangent to a line on a concentration-time graph.  
**c. The instantaneous rate is the slope of the secant to a line on a concentration-time graph.**  
 d. The instantaneous rate decreases over time.

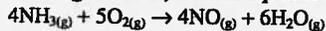
12. Which expression does not represent the rate of the following reaction?



- A  a.  $\frac{\Delta[\text{Mg}]}{\Delta t}$     b.  $\frac{\Delta[\text{H}_2]}{\Delta t}$     c.  $-\frac{1}{2} \left( \frac{\Delta[\text{HCl}]}{\Delta t} \right)$     d.  $\frac{\Delta[\text{MgCl}_2]}{\Delta t}$

$\hookrightarrow \text{Mg}_0$  would not be appearing, it would be disappearing -  $\frac{\Delta[\text{Mg}]}{\Delta t}$

13. In the following reaction, what is equal to the rate of production of NO gas?

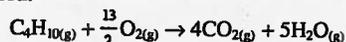


- a. the rate of production of  $\text{NH}_3$  gas  
 b. one third the rate of production of water  
 C  c. four fifths the rate of disappearance of  $\text{O}_2$  gas  
 d. one quarter the rate of disappearance of  $\text{NH}_3$  gas  
 e. six times the production of water vapour

$$r_f = \frac{c r_f}{k r}$$

$$\frac{\Delta[\text{NO}]}{\Delta t} = \frac{-4}{5} \frac{\Delta[\text{O}_2]}{\Delta t}$$

14. In the following reaction, butane is consumed at the rate of  $0.0333 \text{ mol}/(\text{L}\cdot\text{s})$ . Determine the rate at which  $\text{CO}_2$  is produced.



- E  a.  $0.00825 \text{ mol}/(\text{L}\cdot\text{s})$     b.  $0.0165 \text{ mol}/(\text{L}\cdot\text{s})$     c.  $0.0333 \text{ mol}/(\text{L}\cdot\text{s})$     d.  $0.0667 \text{ mol}/(\text{L}\cdot\text{s})$     e.  $0.133 \text{ mol}/(\text{L}\cdot\text{s})$

$$r_f = \frac{c r_f}{k r}$$

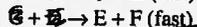
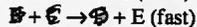
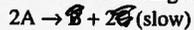
$$\frac{\Delta[\text{CO}_2]}{\Delta t} = \frac{4}{1} \frac{\Delta[\text{C}_4\text{H}_{10}]}{\Delta t} = 4(0.0333)$$

$$= 0.133 \text{ mol}/(\text{L}\cdot\text{s})$$

15. Which statement about the factors that affect reaction rates is false?

- a. Decreasing the concentrations of the reacting particles decreases the chance of collision.  
 b. A collision with poor orientation requires a higher activation energy than a collision with optimum orientation.  
 c. Increasing the pressure in a gaseous reaction increases the chance of collision.  
 D  d. A reaction occurs every time particles of the reactants collide.  
 e. Increasing the temperature increases the reaction rate.

16. Given the following reaction mechanism, what is the equation for the overall reaction? Hess's Law e.g.

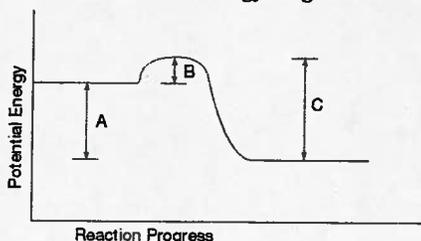


- A  a.  $2\text{A} \rightarrow 2\text{E} + \text{F}$     b.  $2\text{A} + \text{B} + 2\text{C} \rightarrow \text{D} + 2\text{E} + \text{F}$     c.  $2\text{A} + 2\text{C} \rightarrow 2\text{E} + \text{F}$     d.  $2\text{A} + \text{C} \rightarrow 2\text{E} + \text{F}$

17. Which quantity does not increase when the temperature of a reaction system is raised?

- A  a. activation energy    b. # of collisions    c. # of effective collisions    d. average kinetic energy of the particles

\*\* Use the Potential Energy Diagram to answer questions 18 - 20 \*\*



18. Use the Potential Energy Diagram. What is shown by the letter A?

- D  a.  $E_a$  forward    b.  $E_a$  reverse    c. the transition state    d. the heat of reaction

19. Use the Potential Energy Diagram. What is shown by the letter B?

- A  a.  $E_a$  forward    b.  $E_a$  reverse    c. the transition state    d. the heat of reaction

20. Use the Potential Energy Diagram. What is shown by the letter C?

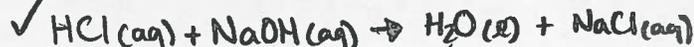
- B  a.  $E_a$  forward    b.  $E_a$  reverse    c. the transition state    d. the heat of reaction

Problems: Choose FIVE of the eight questions for a total of 45 MARKS. Make sure to show ALL of your work. Be sure to include all equations, correct units, and therefore statements. The FIRST five questions attempted will be marked.

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1. A chemist uses a coffee-cup calorimeter to neutralize completely 75.0 mL of 0.67 mol/L HCl with 75 mL of NaOH. The temperature change is 39.6°C.

a) Calculate the heat of neutralization, in kJ/mol of HCl and then write a thermochemical equation for the reaction. [ 19]



$$V = 0.075\text{L} \quad V = 0.075\text{L}$$

$$C = 0.67\text{M} \quad C = 0.67\text{M}$$

$$n_{\text{HCl}} = CV$$

$$= (0.67)(0.075)$$

$$= 0.0503\text{ mol HCl}$$

$$n_{\text{NaOH}} = CV$$

$$= (0.67)(0.075)$$

$$= 0.0503\text{ mol NaOH}$$

$$\frac{1\text{ mol HCl}}{0.0503\text{ mol}} = \frac{1\text{ mol H}_2\text{O}}{x}$$

$$x = 0.0503\text{ mol H}_2\text{O}$$

$$\frac{1\text{ mol NaOH}}{0.0503\text{ mol}} = \frac{1\text{ mol H}_2\text{O}}{x}$$

$$x = 0.0503\text{ mol H}_2\text{O}$$

NO L.R.

$$m_{\text{sol'n}} = CV$$

$$= (1.09\text{ g/ml})(150\text{ ml})$$

$$= 150\text{ g}$$

$$\Delta H_{\text{rxn}} = -\Delta H_{\text{sol'n}}$$

$$= -mc\Delta T$$

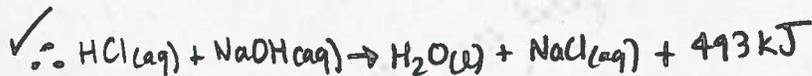
$$= -(150\text{ g})(4.184\text{ J/g}\cdot\text{C})(39.6^\circ\text{C})$$

$$= -24.8\text{ kJ}$$

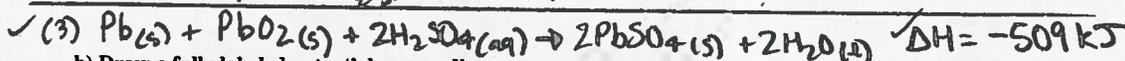
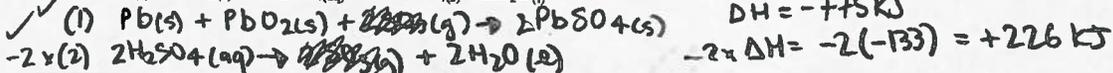
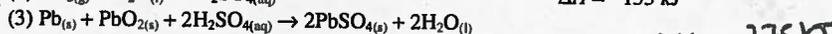
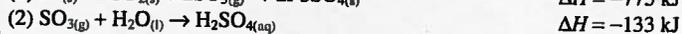
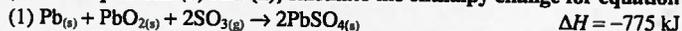
$$\Delta H_1 = \frac{\Delta H_2 n_1}{n_2}$$

$$= \frac{(-24.8)(1)}{0.0503}$$

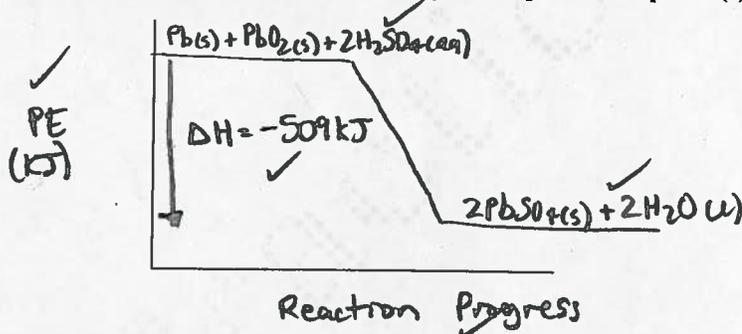
$$= -493\text{ kJ}$$



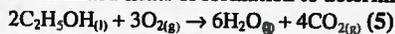
2. a) Given equations (1) and (2), calculate the enthalpy change for equation (4).



b) Draw a fully labeled potential energy diagram to represent the equation (5).



\* 3. a. Use standard heats of formation to determine the heat of combustion for the following reaction.



$$\Delta H_{\text{rxn}} = \sum n \Delta H_f^\circ \text{ products} - \sum n \Delta H_f^\circ \text{ reactants}$$

$$= [6(-241.8) + 4(-393.5)] - [2(-277.6) + 3(0)]$$

$$= -2469.6\text{ kJ}$$

∴  $\Delta H^\circ_{\text{comb}}$  for the above rxn is  $-2469.6\text{ kJ}$

b. Calculate the amount of energy released from combusting 50 g of ethanol. (4)

$$n_{\text{C}_2\text{H}_5\text{OH}} = \frac{m}{M}$$

$$= \frac{50\text{ g}}{46.08\text{ g/mol}}$$

$$= 1.085\text{ mol}$$

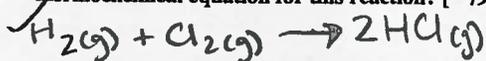
$$\Delta H_2 = \frac{\Delta H_1 n_1}{n_2}$$

$$= \frac{(-2469.6\text{ kJ})(1.085\text{ mol})}{(2)}$$

$$= -1339.8\text{ kJ}$$

∴  $1339.8\text{ kJ}$  is released from combusting 50g of  $\text{C}_2\text{H}_5\text{OH}$

4. The bond energy of  $H_{2(g)}$  is 436.4 kJ/mol and for  $Cl_{2(g)}$  it is 242.7 kJ/mol. The bond energy for the formation of  $HCl_{(g)}$  is 431.9 kJ/mol. What is the standard heat of formation for  $HCl_{(g)}$  based on these values? What is the thermochemical equation for this reaction? [ 19 ]



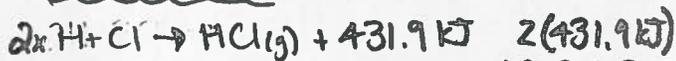
Bonds break

$$H-H + 436.4 \text{ kJ} \rightarrow 2H = 436.4 \text{ kJ}$$

$$Cl-Cl + 242.7 \text{ kJ} \rightarrow 2Cl = 242.7 \text{ kJ}$$

$$\checkmark 679.1 \text{ kJ}$$

Bonds formed

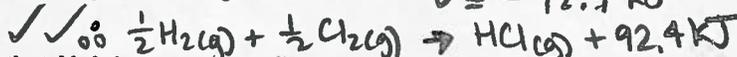


$$\checkmark 863.8 \text{ kJ}$$

$$\checkmark E_{NET} = E_{break} - E_{formed}$$

$$= 679.1 \text{ kJ} - 863.8 \text{ kJ}$$

$$\checkmark = -184.7 \text{ kJ}$$



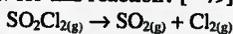
$$\checkmark \Delta H_f = \frac{\Delta H_{rxn}}{n_2}$$

$$= \frac{-184.7 \text{ kJ}}{(1)}$$

(2)

$$\checkmark = -92.4 \text{ kJ}$$

5. The experimental data in the table below were collected for the following decomposition of  $SO_2Cl_{2(g)}$ . What is the rate law for this reaction? [ 19 ]



Trial	Initial concentration of $SO_2Cl_{2(g)}$ (mol/L)	Initial reaction rate [mol/(L·s)]
1	0.100	$2.2 \times 10^{-6}$
2	0.200	$4.4 \times 10^{-6}$
3	0.300	$6.6 \times 10^{-6}$

$$\checkmark \frac{\text{rate } 3}{\text{rate } 1} = \frac{[SO_2Cl_2]_3^m}{[SO_2Cl_2]_1^m}$$

$$\frac{6.6 \times 10^{-6}}{2.2 \times 10^{-6}} = \frac{[0.3]^m}{[0.1]^m}$$

$$\checkmark 3 = 3^m$$

$$\checkmark m = 1$$

for trial 1

$$\checkmark r = k [SO_2Cl_2]^1$$

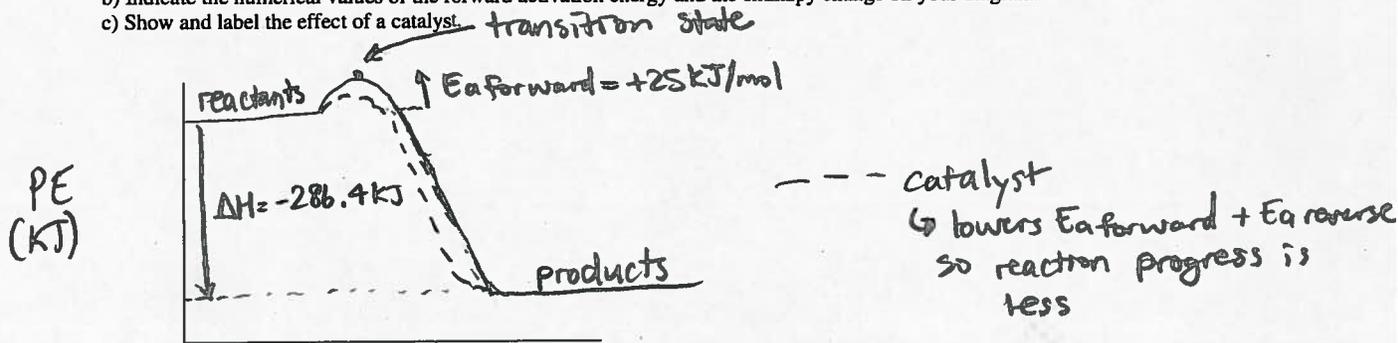
$$\checkmark k = \frac{r}{[SO_2Cl_2]^1}$$

$$= \frac{2.2 \times 10^{-6} \text{ mol/(L·s)}}{0.1 \text{ mol/L}}$$

$$\checkmark = 2.2 \times 10^{-5} \text{ s}^{-1} \checkmark$$

$$\checkmark \therefore \text{the rate law is } r = 2.2 \times 10^{-5} [SO_2Cl_2]^1$$

7. The forward activation energy of a reaction is 25 kJ/mol, and the heat of reaction is -286.4 kJ/mol.
- Sketch a potential energy diagram for the reaction. Label the axes, the forward activation energy, the heat of reaction, the transition state, and the reactants and products.
  - Indicate the numerical values of the forward activation energy and the enthalpy change on your diagram.
  - Show and label the effect of a catalyst.



8. Ethanol,  $C_2H_5OH$ , and gasoline (approximately 100% octane,  $C_8H_{18}$ ) are both used as fuel in cars. If gasoline sells for \$1.15/L, what would the price of ethanol have to be in order to provide the same amount of heat per dollar? The density of octane is 0.7025 g/mL, and  $\Delta H_f^\circ$  of octane is -249.9 kJ/mol. The density of ethanol is 0.7894 g/mL, and  $\Delta H_f^\circ$  of ethanol is -277.6 kJ/mol. [ 19]

Assume a 1 L volume of each fuel.

octane

$$m_{\text{octane}} = DV$$

$$= (0.7025 \text{ g/ml})(1000 \text{ ml})$$

$$\checkmark = 702.5 \text{ g}$$

$$n_{C_8H_{18}} = \frac{m}{M}$$

$$= \frac{702.5 \text{ g}}{114.26 \text{ g/mol}}$$

$$\checkmark = 6.1483 \text{ mol } C_8H_{18}$$

ethanol

$$m_{\text{ethanol}} = DV$$

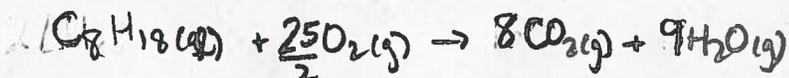
$$= (0.7894 \text{ g/ml})(1000 \text{ ml})$$

$$\checkmark = 789.4 \text{ g}$$

$$n_{C_2H_5OH} = \frac{m}{M}$$

$$= \frac{789.4 \text{ g}}{46.08 \text{ g/mol}}$$

$$\checkmark = 17.131 \text{ mol } C_2H_5OH$$



$$\Delta H_{\text{comb}}^\circ = \sum n \Delta H_f^\circ \text{ products} - \sum n \Delta H_f^\circ \text{ reactants}$$

$$= [8(-393.5) + 9(-241.8)] - [(-249.9) + \frac{25}{2}(0)]$$

$$\checkmark = -5074.3 \text{ kJ/mol}$$

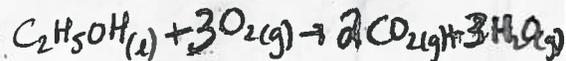
$$\Delta H_2 = \frac{\Delta H_1 n_1}{n_2}$$

$$= \frac{(-5074.3)(6.1483)}{1}$$

$$= -3.12 \times 10^4 \text{ kJ/L } C_8H_{18}$$

$$C_8H_{18} : C_2H_5OH$$

$$\text{\$ cost of ethanol} = \left( \frac{-2.12 \times 10^4}{-3.12 \times 10^4} \right) (1.15) = \text{\$0.78/L}$$



$$\Delta H_{\text{comb}} = \sum n \Delta H_f^\circ \text{ prod} - \sum n \Delta H_f^\circ \text{ react}$$

$$= [2(-393.5) + 3(-241.8)] - [(-277.6)]$$

$$\checkmark = -1235 \text{ kJ/mol } C_2H_5OH$$

$$\Delta H_2 = \frac{\Delta H_1 n_1}{n_2}$$

$$= \frac{(-1235)(17.131)}{1}$$

$$= -2.12 \times 10^4 \text{ kJ/L } C_2H_5OH$$

$$\text{\$0.78/L}$$

$$\text{\% cost of } C_2H_5OH \text{ is } \$0.78/$$