Objective 9: Energy and heat 2: predict heat and work in a chemical reaction and chemical heat transfer. Apply using Hess' law.

Quiz Practice problems:

Key ideas:

Two types of heat:

Physical heat transfer = when a hot object touches a cold object: $q = m\ s\ \Delta T$

Chemical heat transfer = a chemical reaction releases heat (exothermic) to its surroundings or absorbs heat (endothermic) from its surroundings: $q = \Delta H$. Calculate ΔH using Hess' law.

A chemical reaction involves energy.

Hess' law: ΔHreaction = Σ nΔH_f (products) - Σ nΔH_f (reactants) where n = coefficient in moles in balanced chemical equation and ΔH_f = change in enthalpy of formation.

A formation reaction is a reaction in which a substance is formed from elements in the standard state.

Example: formation reaction of liquid water is 2 H_2 (g) + O_2 (g) ---> 2 H_2O (l)

ΔH_f of an element in its standard state = 0 kJ/mole.

ΔH_f of a substance tells us how stable or reactive the substance is.

Example: ΔH_f of H_2 (g) = 0 kJ/mole, ΔH_f of H_2O (l) = -285 kJ/mole.

-285 kJ is a lower energy than 0 kJ so H_2O (l) is more stable or less reactive than H_2 (g).

Skills: Use table of thermodynamic quantities to look up $\Delta H_{formation}$.

Apply Hess' law to calculate $\Delta H_{reaction}$.

Use heat equations, e.g., calculate the amount of water that is heated by a chemical reaction.

1. a. Compare ΔH_f of Cl_2 (g) to Cl^- (aq). Does chlorine exist as element or ion?

b. Compare ΔH_f of H_2O (l) to H_2O (g). Does water exist as a liquid or gas at room temperature?

c. Look up ΔH_f of CO_2 (g). Is CO_2 (g) stable or reactive?

2. a. Is heat absorbed or released when water vaporizes to steam? Calculate ΔH_{rxn} for H_2O (l) ---> H_2O (g) to confirm your answer. How is q related to ΔH_{rxn}?

(Answer: ΔH_f for H_2O (l) = -285 kJ/mole, ΔH_f for H_2O (g) = -241 kJ/mole.

Apply Hess' law, ΔH_{rxn}. = [1 x ΔH_f for H_2O (g)] – [1 x ΔH_f for H_2O (l)] = [-241 kJ/mole] – [-285 kJ/mole] = 44 kJ/mole)

b. Is heat absorbed or released when steam condenses to water? Calculate ΔH_{rxn} for H_2O (g) ---> H_2O (l) to confirm your answer.

c. Is the same amount of heat involved in each phase change?

d. When 100°C steam comes in contact with a 25°C object, the 100°C steam condenses to 100°C H_2O (l) and then the H_2O (l) cools until T_f (thermal equilibrium) is reached.

So the heat lost by steam = (moles steam)(ΔH_{rxn} for H_2O (l) --> H_2O (g)) + (mass of water)(specific heat of water)(ΔT)

When 100°C H_2O (l) comes in contact with a 25°C object, hot H_2O (l) cools until T_f (thermal equilibrium) is reached.

So the heat lost by hot water = _____

Explain why being burned by steam is much worse than being burned by water.

3. In a combustion reaction, a fuel burns (reacts) with O_2 to form water and CO_2 (for a carbon based fuel).

Natural gas, CH_4, is used in gas stoves: CH_4 (g) + O_2 (g) ---> CO_2 (g) + H_2O (g)

a. Balance the equation:

(i) Balance C. 1 C on each side of the equation.

(ii) Balance H. 4 H on reactant side. 2 H on product side. What coefficient should you use for H_2O?

(iii) Balance O. 2 O on reactant side. 4 O on product side (2 from CO_2, 2 from 2 H_2O). What coefficient should you use for O_2?

(iv) Combustion reactions are oxidation-reduction reactions. Which reactant is oxidized? Determine the charge of the element in the reactant and product that is being oxidized.

b. Apply Hess' law to calculate ΔH_{rxn}. (Look up ΔH_f for CH_4 (g) and H_2O (g). Answer: ΔH_{rxn} between -790 to -810 kJ/mole)

c. 0.1 moles of CH_4 is burned to heat up 1 liter of water at 25°C. Calculate the final temperature of the water.

(i) Fill in the blanks: Heat gained by _____ = - heat lost by _____

(ii) Should you use $q = \Delta H$ or $q = ms\Delta T$ for heat gained by ____? (Hint: if a chemical reaction occurs, $q = \Delta H$)

(iii) Should you use $q = \Delta H$ or $q = ms\Delta T$ for heat lost by ____?

(iv) Set up your calculation – it should look like:

> m s ΔT = - moles of _____ x ΔH (in J/mole)
>
> Remember $\Delta T = T_f - T_i$
>
> Solve for T_f. (Answer: T_f is between 40-45°C)

4. Butane, C_4H_{10}, is used in lighters and camping stoves.

a. Write a chemical equation that represents the combustion of butane.

b. Calculate ΔH_{rxn}.
c. Will burning 0.1 moles of butane heat up 1 liter of water at 25°C more or less or the same as burning 0.1 moles of natural gas? Calculate T_f to support your answer.

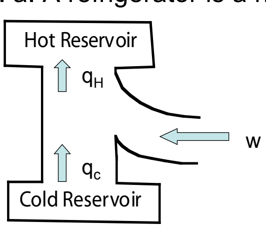
5. You made hot packs and cold packs in lab. An ionic solid is dissolved in water.
a. If the dissolution of an ionic solid is endothermic, the solid is used in a ____ pack.
b. KNO_3 can be used in a cold pack. Write a chemical equation and calculate ΔH_{rxn} to confirm this answer.
c. Calculate the mass of KNO_3 that will lower the temperature of 50 g of water from 25°C to 0°C.

6. Fuels are used to produce work. Work involves gases: $w = -p\ \Delta V$.
When a gas expands ($V_f > V_i$ so $\Delta V = V_f - V_i > 0$), the gas can do work on an object. In other words, the gas produces work so $w = -p\ \Delta V < 0$.
To compress a gas ($V_f < V_i$ so $\Delta V = V_f - V_i < 0$), some thing, e.g., you, have to do work on the gas. In other words, work is supplied to the gas so $w = -p\ \Delta V > 0$.
Is $\Delta V > 0$, < 0, or $= 0$?
Is $w > 0$, < 0, or $= 0$?
a. Explain how a car airbag inflating produces work.
b. You have a 20 ml syringe. You move the plunger to the 10 ml mark. You plug the end of the syringe. You push on the plunger to move it to the 5 ml mark.
(i) Is work produced by the gas or is work supplied to the gas?
(ii) Is work > 0 or < 0? Give reasons.
c. Work is involved in a chemical reaction if a reactant or product is a gas.
Example: Propane (C_3H_8) is used as a fuel.
C_3H_8 (g) + 5 O_2 (g) ---> 3 CO_2 (g) + 4 H_2O (g)
Compare the moles of gas reactants to the moles of gas products: 6 moles of gas reactants --> 7 moles of gas products
Δn = moles of gas products – moles of gas reactants = 7 – 6 = 1 mole
According to ideal gas law, $PV = nRT$. So Δn is directly proportional to ΔV.
If $\Delta n > 0$, then $\Delta V > 0$.
Since $\Delta V > 0$, work must be < 0 (remember $w = -p\Delta V$).
When propane burns, work is produced.

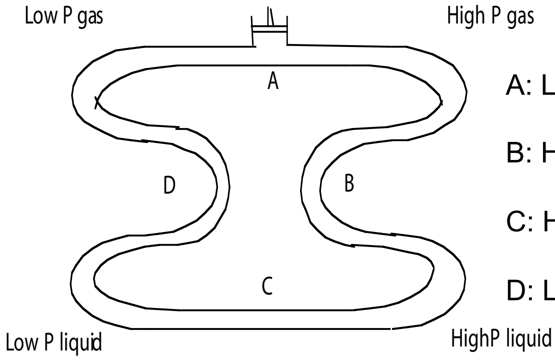
(i) When natural gas (CH_4) burns, is work produced?
Write a balanced chemical equation for the combustion of CH_4.
Compare the moles of gas reactants to the moles of gas products.
Determine Δn.
Determine ΔV.
Determine w.

(ii) A fuel should produce work when used in car engine. Which fuel, propane or natural gas, works better in a car engine? Give reasons.

7. a. A refrigerator is a heat engine in reverse.



(i) Is work produced or supplied?
(ii) What part of the refrigerator is the cold reservoir?
(iii) How is work converted into heat ?
b. A schematic diagram of a refrigerator is shown below.



A: Low P gas --> High P gas

B: High P gas --> High P liq

C: High P liq --> Low P liq

D: Low P liq --> Low P gas

(i) Determine q and w for each step.
(ii) Which step cools air inside the refrigerator?
(iii) Would you want the refrigerant to have a high boiling point or low boiling point? Give reasons.
(iv) Would you want the refrigerant to be compressible or incompressible? Give reasons.