Problem Set #7

CHEM101A: General College Chemistry

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8 Topic D Problem 8

Consider the following two facts about the reaction of HCl with NaOH
Fact #1: ΔE is a negative number for this reaction, which means that the energy of the chemicals decreases.
Fact #2: When HCl and NaOH are mixed, the mixture becomes hotter, which means that the energy of the chemicals increases.

Explain how both of these statements can be true at the same time.

8.1 Solution

The energy in ΔE referes to the potential energy, not the kinetic energy. What likely happened is that the potental energy decreased, so the kinetic energy increased by the potential energy being converted to kinetic energy.

9 Topic D Problem 9

When aqueous HCl reacts with solid $NaHCO_3$, the mixture becomes colder.

a) Does the kinetic energy of the chemicals increase, decrease, or remain the same during the reaction?

b) Does the potential energy of the chemical increase, decrease, or remain the same during the reaction?

c) What is the sign of ΔE for this reaction?

9.1 Solution (a)

The mixture becoming colder implies the temperature decreased, implying the kinetic energy $\boxed{\text{decreased}}$.

9.2 Solution (b)

The total energy of the system would have to remain the same. Since the kinetic energy decreases, the potential energy must increase.

9.3 Solution (c)

Since ΔE refers to the change in potential energy, the sign of ΔE is $\boxed{\text{positive}}$.

10 Topic D Problem 10

For the reaction $2\,\mathrm{Al(s)} + 6\,\mathrm{H^+(aq)} \longrightarrow 2\,\mathrm{Al^{3+}(aq)} + 3\,\mathrm{H_2(g)}$, ΔE = -1057 kJ.

a) How much energy is given off when 2.822 g of Al reacts with hydrogen ions, assuming the hydrogen ions are in excess?

b) How much energy is given off when 1.413 g of Al is added to 23.0 mL of a solution that contains 5.89 M $\mathrm{H^+}$?

c) If you want to obtain 50.0 kJ of energy from this reaction, how many grams of aluminum and how many mL of 3.00 M HCl must you use?

d) If this reaction produces 13.3 L of $\mathrm{H_2(g)}$ at 25.0°C and 1.014 atm, how much energy does it give off?

10.1 Solution (a)

First convert grams to moles.

$$MM(\mathrm{Al}) = 26.98\,\mathrm{g/mol} \tag{1}$$

$$n(\mathrm{Al}) = \frac{m}{MM} = \frac{2.822\,\mathrm{g}}{26.98\,\mathrm{g/mol}} = 0.\underline{1045}95997\,\mathrm{mol} \tag{2}$$

Next, we use our favorite ratio for energy.

$$\frac{\Delta \mathrm{E_{sp}}}{\mathrm{n_{sp}(Al)}} = \frac{\Delta \mathrm{E}}{\mathrm{n(Al)}} \tag{3}$$

$$\frac{\Delta E_{sp}}{0.\underline{1045}9\,\mathrm{mol}} = \frac{-1057\,\mathrm{kJ}}{2\,\mathrm{mol}} = -\underline{528.5}\mathrm{kJ/mol} \tag{4}$$

$$\Delta E = -\underline{55.27}898\,\mathrm{kJ} \tag{5}$$

This means that it releases $\boxed{55.28\,\mathrm{kJ}}$.

10.2 Solution (b)

First, find the limiting reactant.

$$n(\mathrm{Al}) = \frac{m}{MM} = \frac{1.413\,\mathrm{g}}{26.98\,\mathrm{g/mol}} = 0.0\underline{5231}7\,\mathrm{mol\,Al} \tag{6}$$

$$n(\mathrm{H^+}) = cV = (5.89\,\mathrm{mol/L})(23.0\,\mathrm{mmol}) = 0.\underline{135}47\,\mathrm{mol\,H^+} \tag{7}$$

Dividing the number of moles of $\mathrm{H^+}$ by 6 and the number of moles of Al by 2 makes clear that the $\mathrm{H^+}$ is the limiting reactant. From here, just use our favorite ratio again.

$$\frac{\Delta E_{sp}}{0.\underline{135}47\,\mathrm{mol}} = \frac{-1057\,\mathrm{kJ}}{6\,\mathrm{mol}} = 176.167\,\mathrm{kJ/mol} \tag{8}$$

$$\Delta E_{sp} = \underline{23.8}653\,\mathrm{kJ} \tag{9}$$

That means it releases $\boxed{23.9\,\mathrm{kJ}}$.

10.3 Solution (c)

In this instance, it would have to be that $\Delta E_{sp} = -50.0\text{kJ}$. We can put this into our favorite ratio to find the number of necessary moles of each.

$$\frac{-50.0\,\text{kJ}}{n(\text{Al})} = \frac{-1057\,\text{kJ}}{2\,\text{mol}} \tag{10}$$

$$n(\text{Al}) = \frac{50.0\,\text{kJ}}{528.5\,\text{kJ/mol}} = 0.0\underline{946}0738\,\text{mol} \tag{11}$$

$$\frac{-50.0\,\text{kJ}}{n(\text{H}^+)} = \frac{-1057\,\text{kJ}}{6\,\text{mol}} \tag{12}$$

$$n(\text{H}^+) = \frac{50.0\,\text{kJ}}{\underline{176.1}667\,\text{kJ/mol}} = 0.\underline{283}8221\,\text{mol} = n(\text{HCl}) \tag{13}$$

Now we can convert both to their requested units.

$$m(\text{Al}) = n * MM = 0.0\underline{946}0738\,\text{mol} * 26.98\,\text{g/mol} \tag{14}$$

$$= \boxed{2.55\,\text{g}} \tag{15}$$

$$V(\text{H}^+) = \frac{n}{M} = \frac{0.\underline{283}8221\text{ mol}}{3.00\text{ M HCl}} = \boxed{0.0946\,\text{L}} \tag{16}$$

10.4 Solution (d)

Use the ideal gas law to find the number of moles.

$$PV = nRT \tag{17}$$

$$n = \frac{PV}{RT} = \frac{(1.014\,\text{atm})(13.3\,\text{L})}{(0.08206\,\text{atm}\cdot\text{L/mol}\cdot\text{K})(298.15\,\text{K})} \tag{18}$$

$$= 0.\underline{551}2178\,\text{mol} \tag{19}$$

This can be used with our favorite ratio.

$$\frac{\Delta E_{sp}}{n_{sp}(\text{H}_2)} = \frac{\Delta E}{n(\text{H}_2)} \tag{20}$$

$$\frac{\Delta E_{sp}}{0.\underline{551}2178\,\text{mol}} = \frac{-1057\,\text{kJ}}{3\,\text{mol}} = -\underline{352}.333\,\text{kJ/mol} \tag{21}$$

$$\Delta E_{sp} = (0.\underline{551}2178\,\text{mol})(-\underline{352}.333\,\text{kJ/mol}) = \underline{194.2}1\,\text{kJ} = \boxed{194.2\,\text{kJ}} \tag{22}$$

11 Topic D Problem 11

When 4.00 g of Br_2 reacts with excess Al to form $AlBr_3$, 8.80 kJ of energy is given off. Calculate ΔE for the reaction $2\,\mathrm{Al(s)} + 3\,\mathrm{Br_2(s)} \longrightarrow 2\,\mathrm{AlBr_3(s)}$.

11.1 Solution

First convert the number of grams of Br_2 to moles.

$$n(\mathrm{Br_2}) = \frac{4.00\,\mathrm{g}}{159.8\,\mathrm{g/mol}} = 0.0\underline{250}313\,\mathrm{mol} \tag{23}$$

Next, use our favorite fraction.

$$\frac{\Delta E}{n(Br2)} = \frac{\Delta E_{sp}}{n_{sp}(Br2)} \tag{24}$$

$$\frac{\Delta E}{3\,\mathrm{mol}} = \frac{-8.80\,\mathrm{kJ}}{0.0\underline{250}313\,\mathrm{mol}} = -\underline{351}.56\,\mathrm{kJ/mol} \tag{25}$$

$$\Delta E = (3\,\mathrm{mol})(\underline{351}.56\,\mathrm{kJ/mol}) = -\underline{105}4.68\,\mathrm{kJ} = \boxed{-1.054\,\mathrm{MJ}} \tag{26}$$

12 Topic D Problem 12

A chemist burns 0.5177 g of liquid hexane (C_6H_{14}) in a bomb calorimeter that has a heat capacity of 4287 J/°C. The temperature of the calorimeter rises from 21.382°C to 27.170°C during the reaction. Calculate ΔE for the following reaction:

$$2\,C_6H_{14}(l) + 19\,O_2(g) \longrightarrow 12\,CO_2(g) + 14\,H_2O\,(l)$$

12.1 Solution

$C = 4287\ J/°C$; $\Delta T = 27.170°C - 21.382°C = \underline{5.788}\ °C$

$m(C_6H_{14}) = 0.5177\ g$; $MM(C_6H_{14}) = 6 \times 12.01 + 14 \times 1.008 = 86.172\ g/mol$

$n_{sp}(C_6H_{14}) = \dfrac{m}{MM} = \dfrac{0.5177}{86.172} = 0.0060078\ mol$

$\Delta E_{sp} = C\,\Delta T = 5.788°C \times 4287\ J/°C = 24.813\ kJ$

Our favorite ratio

$\dfrac{\Delta E}{n(C_6H_{14})} = \dfrac{\Delta E_{sp}}{n_{sp}(C_6H_{14})} = \dfrac{24.813\ kJ}{0.0060078\ mol} = 4.130189\ MJ/mol$

$\Delta E = 4.130189\ MJ/mol \times 2\ mol = 8.260\ MJ$

Since the temperature rises, energy is released, so ΔE is negative

$\boxed{\Delta E = -8.260\ MJ}$

13 Topic D Problem 13

Explain why some reactions give off different amounts of heat when they are carried out at constant pressure versus constant volume.

13.1 Solution

I just did Thermodynamics in Physics, so that's the perspective I'm approaching this from.

$$W = P\Delta V \tag{27}$$

When you carry out a reaction at constant pressure, the volume can still change. This volume change allows work to be done because the work depends on the change in volume but only the raw value of the pressure. Meanwhile, when you carry out a reaction at constant volume, no work can be done because the work is dependant on the change in volume, not the raw value.

14 Topic D Problem 14

A reaction has ΔE = -50 kJ.

a) If this reaction occurs, will the reaction mixture become hotter, or colder?

b) Is this an exothermic reaction, or is it an endothermic reaction?

c) After this reaction has occurred, will the potential energy of the chemical mixture be higher than, lower than, or the same as it was before the reaction?

d) After this reaction has occurred, will the kinetic energy of the universe be higher than, lower than, or the same as it was before the reaction (assuming no other reaction has occurred)?

14.1 Solution

a) Immediately, the mixture will become <u>hotter</u>, but the temperature will even out to equilibrium over time.

b) Since the energy causes the mixture to warm up and exert energy from within, the process would be <u>exothermic</u>.

c) It would be <u>lower</u>.

d) The kinetic energy of the universe will <u>increase</u>.

15 Topic D Problem 15

A reaction has $\Delta E = 10$ kJ, and it converts a solid into a gas.

a) If this reaction occurs in a closed, rigid container, will the amount of heat that is absorbed be larger than 10 kJ, smaller than 10 kJ, or exactly 10 kJ? Justify your answer.

b) If this reaction occurs in an open container, will the amount of heat that is absorbed be larger than 10 kJ, smaller than 10 kJ, or exactly 10 kJ? Justify your answer.

c) Will PV work be done in either part a or part b? If so, which part(s)?

d) What is the sign of the PV work when PV work occurs?

15.1 Solution

a/ In a closed container (constant volume), it would be <u>equal to</u> 10 kJ because the constant volume eliminates any PV work to near zero.

b/ In an open container, it would be <u>more than</u> 10 kJ because energy change will be constant and negative work will be done on the gas so the heat will have to make up for that work.

c/ PV work will be done in part (b) but not part (a).

d/ The sign of the PV work would be negative.

16 Topic D Problem 16

A reaction has ΔE = -10 kJ, and it converts a gas into a liquid.

a) If this reaction occurs in a closed, rigid container, will the amount of heat that is given off be larger than 10 kJ, smaller than 10 kJ, or exactly 10 kJ? Justify your answer.

b) If this reaction occurs in an open container, will the amount of heat that is given off be larger than 10 kJ, smaller than 10 kJ, or exactly 10 kJ? Justify your answer.

c) Will PV work be done in either part a or part b? If so, which part(s)?

d) What is the sign of the PV work when PV work occurs?

16.1 Solution

a/ In a closed container, the heat given off will be <u>exactly</u> 10 kJ because the constant volume eliminates any PV work to near zero.

b/ Since gas is lost, the work done on the gas will be positive, so the heat gained will be less than -10 kJ. Since this is about heat given off rather than heat absorbed, the heat lost would be the negative of the aforementioned and <u>more than</u> 10 kJ.

c/ In part (b), work will be done on the gas.

d/ Positive.

17 Topic D Problem 17

A reaction has ΔE = -10 kJ, and it converts a liquid into a gas.

a) If this reaction occurs in a closed, rigid container, will the amount of heat that is given off be larger than 10 kJ, smaller than 10 kJ, or exactly 10 kJ? Justify your answer.

b) If this reaction occurs in an open container, will the amount of heat that is given off be larger than 10 kJ, smaller than 10 kJ, or exactly 10 kJ? Justify your answer.

c) Will PV work be done in either part a or part b? If so, which part(s)?

d) What is the sign of the PV work when PV work occurs?

17.1 Solution

a/ With a constant volume condition (like this one), the energy lost will be equal to the heat lost. In this instance, the heat given off will be equal to 10 kJ.

b/ There will be an increase in moles of gas. This means there will be a certain negative amount of work done, so the heat absorbed will have to be greater than -10 kJ. This means that the heat exerted will have to be less than 10 kJ.

c/ Part (b).

d/ Negative.

18 Topic D Problem 18

a) What is the PV work when 3.00 moles of liquid water boils at 100°C at constant pressure? Give your answer in kJ, and include the correct sign.
b) What is the PV work when 3.00 moles of steam condenses at 100°C at constant pressure? Give your answer in kJ, and include the correct sign.

18.1 Solution

a/ $W = -P\Delta V = -RT\,\Delta n$ $\quad T = 100°C = 373.15\,K$

$= -8.314 \times 373.15 \times 3\,mol = -9.307\,kJ = \boxed{-9.31\,kJ}$

b/ $W = -P\Delta V = -RT\Delta n$

$= -8.314 \times 373.15 \times (-3\,mol) = 9.307\,kJ = \boxed{9.307\,kJ}$

19 Topic D Problem 19

Consider the following reaction:

$$4\,C_3H_9N\,(l) + 21\,O_2(g) \longrightarrow 12\,CO_2(g) + 18\,H_2O\,(l) + 2\,N_2(g)\ \Delta E = \text{-9667 kJ}$$

The following questions (parts a through j) refer to this reaction.

a) Calculate ΔH for this reaction at 25°C.

b) How much heat will be given off if 8.250 g of C_3H_9N reacts with excess O_2 in a closed, rigid container at 25°C?

c) How much heat will be given off if 8.250g of C_3H_9N reacts with excess O_2 in an open container at 25°C?

d) Calculate the PV work in part b. Include the correct sign.

e) Calculate the PV work in part c. Include the correct sign.

f) If you want to obtain 200.0 kJ of heat by reacting C_3H_9N with O_2 in an open container, what mass of C_3H_9N must you use?

g) How much heat is produced when 2.199 g of liquid C_3H_9N reacts with 5.738 g of gaseous O_2 in an open container?

h) If you burn enough liquid C_3H_9N to produce 841.2 kJ of heat in an open container, what volume of gaseous N2 will you form at 25.0°C and 752 torr?

i) If this reaction is carried out in a closed, rigid container and produces 31.74 g of liquid H_2O, how much heat does it produce?

19.1 Solution

a/ $\Delta H = \Delta E + RT\,\Delta n_{gas}$ $\quad T = 25°C = 298.15\,K$

$\Delta n_{gas} = n_f - n_i = 12 + 2 - 21 = -7\ mol$

$\Delta H = -9667\,kJ + 8.314 \times 298.15 \times (-7)$

$= -9667\,kJ - 17351\,J = \boxed{-9684\,kJ}$

b/ ΔH and ΔE are directly related to Δn_{gas}

$MM(C_3H_9N) = 3 \times 12.01 + 9 \times 1.009 + 14.01 = 59.112\,g/mol$

$n(C_3H_9N) = \frac{m}{MM} = \frac{8.250\,g}{59.112\,g/mol} = 0.139566\ mol$

$\frac{\Delta E_{sp}}{n_{sp}} = \frac{\Delta E}{n} = \frac{-9.667\,MJ}{4\,mol} = -2.41675\ MJ/mol$

$\Delta E_{sp} = -2.41675 \times 0.13957 = -0.337295\,MJ = \boxed{-337.3\,kJ}$

c/ $\frac{\Delta H_{sp}}{n_{sp}} = \frac{\Delta H}{n} = \frac{-9684\,kJ}{4\,mol} = -2421\ kJ/mol$

$\Delta H_{sp} = -2421\ kJ/mol \times 0.13957\ mol$

$= -337.888\,kJ = \boxed{-337.9\,kJ}$

d/ $W = -RT\,\Delta n_{gas}$ X

$\Delta n_{gas,sp} = (-7\,mol) \times \left(\frac{0.139566\ mol}{12\ mol}\right) = -0.08141325\ mol$

$W = -8.314 \times 298.15 \times (-0.08141325) = 201.8\,J$

d/ $W = -P\Delta V = \boxed{0\,kJ}$

e/ $W = \Delta E - \Delta H = -337.3 + 337.9 = \boxed{0.6\,kJ}$

f/ $\frac{\Delta H_{sp}}{n_{sp}} = \frac{\Delta H}{n} \rightarrow \frac{n_{sp}}{\Delta H_{sp}} = \frac{n}{\Delta H} = \frac{4\ mol}{-9667\,kJ} = -0.000413052\,mol/kJ$

$n = -0.000413052\ mol/kJ \times (-200\,kJ) = 0.0826105\,mol$

$m = n \times MM = 0.08261\ mol \times 59.112\,g/mol = \boxed{4.883\,g}$

g/ $n^{(C_3H_9N)} = \frac{m}{MM} = \frac{2.199\,g}{59.112\,g/mol} = 0.4301643\ mol\ C_3H_9N$

$n(O_2) = \frac{m}{MM} = \frac{5.738\,g}{32.00\,g/mol} = 0.1793125\ mol\ O_2$

$\frac{n(C_3H_9N)}{4} = \frac{0.4302\,mol}{4} = 0.1075 > 0.0085 = \frac{0.1793\,mol}{21} = \frac{n(O_2)}{12}$

O_2 is LR

Open container → use ΔH not ΔE

$\frac{\Delta H_{sp}}{n_{sp}} = \frac{\Delta H}{n} = \frac{-9684\,kJ}{21\,mol} = -461.1429\ kJ/mol$

$\Delta H_{sp} = 0.1793125 \times (-461.1429) = -82.6887\,kJ = \boxed{-82.69\,kJ}$

h/ Our favorite ratio

$\frac{n_{sp}}{\Delta H_{sp}} = \frac{n}{\Delta H} = \frac{2\,mol}{-9684\,kJ} \rightarrow n_{sp} = \frac{n \times \Delta H_{sp}}{\Delta H}$

$PV = nRT \longrightarrow V_{sp} = \frac{n_{sp}\,RT}{P} = \frac{n \times \Delta H_{sp} \times RT}{\Delta H \times P}$

$V_{sp} = \frac{2 \times (-841.2) \times 62.36 \times 298.15}{(-9684) \times 752} = \frac{31280247.44}{7282368}\ L$

$= \boxed{4.295\ L}$

i/ $\Delta E = \Delta H$ for closed container

$n_{sp}(H_2O) = \frac{m}{MM} = \frac{31.74\,g}{18.016\,g/mol}$

$\frac{\Delta E_{sp}}{n_{sp}} = \frac{\Delta E}{n} \Rightarrow \Delta E_{sp} = \frac{n_{sp} \times \Delta E}{n} = \frac{m \times \Delta H}{MM(H_2O) \times n} = \frac{31.74\,g \times (-9.667\,MJ)}{18.016\,g/mol \times 18\,mol}$

$= \frac{-306830.58}{324.288} = -946.2\ kJ$

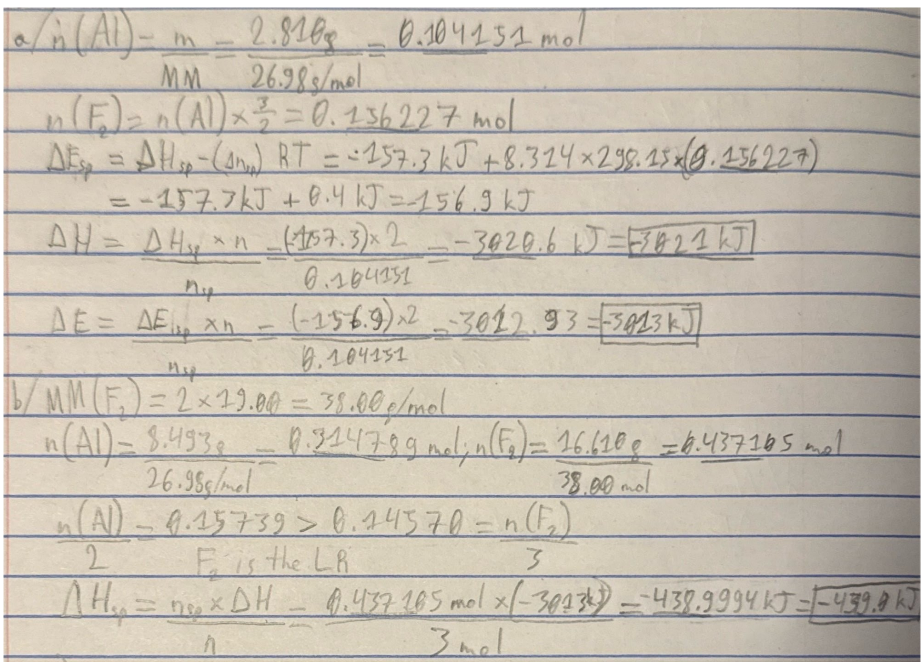
The total heat released is $\boxed{946.2\,kJ}$

20 Topic D Problem 20

When 2.810 g of solid Al reacts with excess gaseous F_2 in an open container at 25°C, 157.3 kJ of heat is produced.

1. Calculate ΔH and ΔE for the following reaction at 25°C:
   $2\,Al(s) + 3\,F_2(g) \longrightarrow 2\,AlF_3(s)$
2. How much heat will be produced if 8.493 g of solid Al reacts with 16.610 g of gaseous F_2 in a closed, rigid container at 25°C? Use your answer from part a to solve this problem.

20.1 Solution



a/ $n(Al) = \frac{m}{MM} = \frac{2.810\,g}{26.98\,g/mol} = 0.104151\ mol$

$n(F_2) = n(Al) \times \frac{3}{2} = 0.156227\ mol$

$\Delta E_{sp} = \Delta H_{sp} - (\Delta n_{sp})RT = -157.3\,kJ + 8.314 \times 298.15 \times (0.156227)$

$= -157.7\,kJ + 0.4\,kJ = -156.9\,kJ$

$\Delta H = \frac{\Delta H_{sp} \times n}{n_{sp}} = \frac{(-157.3) \times 2}{0.104151} = -3020.6\,kJ = \boxed{-3021\,kJ}$

$\Delta E = \frac{\Delta E_{sp} \times n}{n_{sp}} = \frac{(-156.9) \times 2}{0.104151} = -3012.93 = \boxed{-3013\,kJ}$

b/ $MM(F_2) = 2 \times 19.00 = 38.00\,g/mol$

$n(Al) = \frac{8.493\,g}{26.98\,g/mol} = 0.314789\ mol$; $n(F_2) = \frac{16.610\,g}{38.00\,mol} = 0.437105\ mol$

$\frac{n(Al)}{2} = 0.15739 > 0.14570 = \frac{n(F_2)}{3}$

F_2 is the LR

$\Delta H_{sp} = \frac{n_{sp} \times \Delta H}{n} = \frac{0.437105\,mol \times (-3013\,kJ)}{3\,mol} = -438.9994\,kJ = \boxed{-439.0\,kJ}$

21 Topic D Problem 21

A chemist burns 1.628 g of liquid isopropyl alcohol (C_3H_8O) in a bomb calorimeter that has a heat capacity of 3927 J/°C. The temperature of the calorimeter rises from 19.085°C to 31.683°C during the reaction. Calculate ΔH and ΔE for the following reaction at 25°C:

$2\,C_3H_8O\,(l) + 9\,O_2(g) \longrightarrow 6\,CO_2(g) + 8\,H_2O\,(l)$

21.1 Solution

$$Q_{sp} = \Delta E_{sp} = -(3927\ J/C°)(31.683 - 19.085) = -49472.346\ J$$

$$MM(C_3H_8O) = 3 \times 12.01 + 8 \times 1.008 + 16.00 = 60.094\ g/mol$$

$$n_{sp} = \frac{1.628\ g}{60.094\ g/mol} = 0.02709089\ mol$$

$$\Delta E = \frac{n\ \Delta E_{sp}}{n_{sp}} = \frac{2 \times (-49472.346)}{0.02709089\ mol} = -36523223\ J = \boxed{-3652\ kJ}$$

$$\Delta H = \Delta E + RT\,\Delta n_{gas} = -3652\ kJ + (8.314) \times (298.15) \times (-3)$$

$$= -3652\ kJ - 7.436\ kJ = -3659.44\ kJ = \boxed{-3659\ kJ}$$

22 Topic D Problem 22

For the reaction $2\,C(s) + O_2(g) \longrightarrow 2\,CO(g)$, ΔE = -219 kJ. When will ΔH also be -219 kJ?
a) When the reaction is carried out in an open container.
b) When the reaction is carried out in a closed, rigid container.
c) ΔH will always equal ΔE.
d) ΔH will never equal ΔE.

22.1 Solution

There is a constant value of ΔH.

$$\mathrm{\Delta H = \Delta E + RT\Delta n_{gas}} \tag{28}$$

Since $\mathrm{\Delta n_{gas}} = 1\,\mathrm{mol}$ regardless of the conditions of the reactions, ΔH will never be equal to ΔE. The only thing that will differ based on the consdition is whch wone you should use. For constant volume, you should use ΔE, while for constant pressure you should use ΔH. The answer is $\boxed{(d)}$.

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