Problem Set #8

CHEM101A: General College Chemistry

Donald Aingworth IV

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23 Topic D Problem 23

Using the enthalpies of formation in **T1: Standard Thermodynamic Quantities** of your online textbook, calculate the amount of heat that will be released when 5.00 g of solid $NaNO_3$ reacts with excess graphite in an open container. The chemical equation for this reaction is:

$$4\,\mathrm{NaNO_3(s)} + 5\,\mathrm{C(s, graphite)} \longrightarrow 2\,\mathrm{Na_2O\,(s)} + 2\,\mathrm{N_2(g)} + 5\,\mathrm{CO_2(g)}$$

23.1 Solution

We can divide this reaction into two separate parts: the decomposition of the $NaNO_3$ and the recomposition of Na_2O and CO_2.

$$\mathrm{NaNO_3(s)} \longrightarrow \mathrm{Na\,(s)} + \frac{1}{2}\mathrm{N_2\,(g)} + \frac{3}{2}\mathrm{O_2(g)}, \Delta\mathrm{H} = 467.9 \text{ kJ/mol} \quad (1)$$

$$2\,\mathrm{Na\,(s)} + \frac{1}{2}\mathrm{O_2\,(g)} \longrightarrow \mathrm{Na_2O(s)}, \Delta\mathrm{H} = -414.2 \text{ kJ/mol} \quad (2)$$

$$\mathrm{C(s, graphite)} + \mathrm{O_2(g)} \longrightarrow \mathrm{CO_2(g)}, \Delta\mathrm{H} = -393.5 \text{ kJ/mol} \quad (3)$$

Multiply the first by four, the second by two, and the third by five.

$$4\,\mathrm{NaNO_3(s)} \longrightarrow 4\,\mathrm{Na\,(s)} + 2\,\mathrm{N_2(g)} + 6\,\mathrm{O_2(g)}, \Delta\mathrm{H} = 1871.6 \text{ kJ/mol} \quad (4)$$

$$4\,\mathrm{Na\,(s)} + \mathrm{O_2(g)} \longrightarrow 2\,\mathrm{Na_2O(s)}, \Delta\mathrm{H} = -828.4 \text{ kJ/mol} \quad (5)$$

$$5\,\mathrm{C(s, graphite)} + 5\,\mathrm{O_2(g)} \longrightarrow 5\,\mathrm{CO_2(g)}, \Delta\mathrm{H} = -1967.5 \text{ kJ/mol} \quad (6)$$

Add all of these together. for the sake of simplification, I will denote the cancelations out early.

$$4\,\mathrm{NaNO_3(s)} \longrightarrow \cancel{4Na(s)} + 2\,\mathrm{N_2(g)} + \cancel{6O_2(g)}, \Delta\mathrm{H} = 1871.6 \text{ kJ/mol} \quad (7)$$

$$\cancel{4Na(s)} + \cancel{O_2(g)} \longrightarrow 2\,\mathrm{Na_2O(s)}, \Delta\mathrm{H} = -828.4 \text{ kJ/mol} \quad (8)$$

$$5\,\mathrm{C(s, graphite)} + \cancel{5O_2(g)} \longrightarrow 5\,\mathrm{CO_2(g)}, \Delta\mathrm{H} = -1967.5 \text{ kJ/mol} \quad (9)$$

$$4\,\mathrm{NaNO_3(s)} + 5\,\mathrm{C(s, graphite)} \longrightarrow 2\,\mathrm{Na_2O\,(s)} + 2\,\mathrm{N_2(g)} + 5\,\mathrm{CO_2(g)} \quad (10)$$

The total enthalpy would be the sum of all enthalpies.

$$\Delta H = \Delta H_1 + \Delta H_2 + \Delta H_3 = -924.3\,\mathrm{kJ/mol} \quad (11)$$

Now convert the 5 grams of solid $NaNO_3$ to moles.

$$MM(\mathrm{NaNO_3}) = 22.99 + 14.01 + 48.00 = 85.00\,\mathrm{g/mol} \quad (12)$$

$$n(\mathrm{NaNO_3}) = \frac{m}{MM} = \frac{5.00\,\mathrm{gram}}{85.00\,\mathrm{g/mol}} = 0.0588\,\mathrm{mol} \quad (13)$$

Multiply this by the enthalpy to find the heat.

$$Q = \frac{n * \Delta H}{n_{\mathrm{NaNO_3}}} = \frac{0.0588\,\mathrm{mol} * (-924.3\,\mathrm{kJ/mol})}{4} = -13.6\,\mathrm{kJ} \quad (14)$$

Since it's negative, that means it releases $\boxed{13.6\,\mathrm{kJ}}$.

24 Topic D Problem 24

Pyrrole (C_4H_5N) is a liquid that reacts with oxygen as follows:

$$4\,C_4H_5N\,(l) + 21\,O_2(g) \longrightarrow 16\,CO_2(g) + 10\,H_2O\,(l) + 2\,N_2(g), \Delta H = -9407\,kJ$$

Using this information and the enthalpies of formation in **T1: Standard Thermodynamic Quantities** of your online textbook, calculate the enthalpy of formation (ΔH_f°) of $C_4H_5N\,(l)$.

24.1 Solution

New equations we'll use:

$$C(s, graphite) + O_2(g) \longrightarrow CO_2(g), \quad \Delta H = -393.5\,kJ$$

$$H_2(g) + \tfrac{1}{2}O_2(g) \longrightarrow H_2O(l), \quad \Delta H = -285.8\,kJ$$

Target equation:

$$4C(s, graphite) + \tfrac{5}{2}H_2(g) + \tfrac{1}{2}N_2(g) \longrightarrow C_4H_5N(l)$$

Let's use a matrix.

$$\begin{array}{cccccccc} C & H_2 & O_2 & N_2 & CO_2 & H_2O & C_4H_5N & \Delta H \\ \end{array}$$
$$\left[\begin{array}{ccccccc|c} 0 & 0 & -21 & 2 & 16 & 10 & -4 & -9407 \\ -1 & 0 & -1 & 0 & 1 & 0 & 0 & -393.5 \\ 0 & -1 & -\frac{1}{2} & 0 & 0 & 1 & 0 & -285.8 \end{array}\right]$$
$$\left(\begin{array}{ccccccc} -4 & -\frac{5}{2} & 0 & -\frac{1}{2} & 0 & 0 & 1 \end{array}\right) \leftarrow \text{Target}$$

$$\left[\begin{array}{ccccccc|c} 0 & 0 & -21 & 2 & 16 & 10 & -4 & -9407 \\ -1 & 0 & -1 & 0 & 1 & 0 & 0 & -393.5 \\ 0 & -1 & -\frac{1}{2} & 0 & 0 & 1 & 0 & -285.8 \end{array}\right] \xrightarrow[R_2 \times 4]{R_1 \times -1} \left[\begin{array}{ccccccc|c} 0 & 0 & 21 & -2 & -16 & -10 & 4 & 9407 \\ -4 & 0 & -4 & 0 & 4 & 0 & 0 & -1574 \\ 0 & -1 & -\frac{1}{2} & 0 & 0 & 1 & 0 & -285.8 \end{array}\right]$$

$$\xrightarrow[R_3 \times \frac{5}{2}]{R_1 \div 4} \left[\begin{array}{ccccccc|c} 0 & 0 & \frac{21}{4} & -\frac{1}{2} & -4 & -\frac{5}{2} & 1 & 2351.75 \\ -4 & 0 & -4 & 0 & 4 & 0 & 0 & -1574 \\ 0 & -\frac{5}{2} & -\frac{5}{4} & 0 & 0 & \frac{5}{2} & 0 & -714.5 \end{array}\right]$$

$$\xrightarrow{R_2 + R_3 + R_1} \left[\begin{array}{ccccccc|c} 0 & 0 & \frac{21}{4} & -\frac{1}{2} & -4 & -\frac{5}{2} & 1 & 2351.75 \\ -4 & -\frac{5}{2} & 0 & -\frac{1}{2} & 0 & 0 & 1 & 63.25 \\ 0 & -\frac{5}{2} & -\frac{5}{4} & 0 & 0 & \frac{5}{2} & 0 & -714.5 \end{array}\right]$$

$$\Delta H_f^\circ = \boxed{63\,kJ}$$

25 Topic D Problem 25

For the reaction $4\,K(s) + O_2(g) \longrightarrow 2\,K_2O(s), \Delta H = -722\,kJ$. Using this information, calculate ΔH for each of the following three reactions.

a) $12\,K(s) + 3\,O_2(g) \longrightarrow 6\,K_2O(s)$

b) $K(s) + \frac{1}{4}\,O_2(g) \longrightarrow \frac{1}{2}\,K_2O(s)$

c) $12\,K_2O(s) \longrightarrow 24\,K(s) + 6\,O_2(g)$

25.1 Solution

a/ Multiply by 3

$12K(s) + 3\,O_2(g) \rightarrow 6\,K_2O(s)$, $\Delta H = \boxed{-2166\,kJ}$

b/ Divide by 4

$K(s) + \frac{1}{4}O_2(g) \rightarrow \frac{1}{2}K_2O(s)$, $\Delta H = \boxed{-180.5\,kJ}$

c/ Multiply by -6

$12\,K_2O(s) \rightarrow 24K(s) + 6O_2(g)$, $\Delta H = \boxed{4332\,kJ}$

26 Topic D Problem 26

Given the following chemical reactions and ΔH values:

$$3\,Ag^{+}(aq) + PO_4{}^{3-}(aq) \longrightarrow Ag_3PO_4(s) \qquad \Delta H = -32.7\,kJ$$
$$Ag^{+}(aq) + Cl^{-}(aq) \longrightarrow AgCl\,(s) \qquad \Delta H = -65.5\,kJ$$

Calculate ΔH for the chemical reaction below:

$$Ag_3PO_4(s) + 3\,Cl^{-} \longrightarrow 3\,AgCl(s) + PO_4{}^{3-}(aq)$$

26.1 Solution

Matrix form

$$\begin{array}{c} \begin{array}{cccccc} Ag^{+} & PO_4^{3-} & Cl^{-} & Ag_3PO_4 & AgCl & \Delta H \end{array} \\ \left[\begin{array}{ccccc|c} -3 & -1 & 0 & 1 & 0 & -32.7 \\ -1 & 0 & -1 & 0 & 1 & -65.5 \end{array}\right] \end{array}$$

Target: $(0 \quad 1 \quad -3 \quad -1 \quad 3)$

$$\left[\begin{array}{ccccc|c} -3 & -1 & 0 & 1 & 0 & -32.7 \\ -1 & 0 & -1 & 0 & 1 & -65.5 \end{array}\right] \begin{array}{l} \times(-1) \\ \times 3 \end{array} \longrightarrow \left[\begin{array}{ccccc|c} +3 & +1 & 0 & -1 & 0 & +32.7 \\ -3 & 0 & -3 & 0 & 3 & -196.5 \end{array}\right]$$

$$\xrightarrow{+R_1} \left[\begin{array}{ccccc|c} 3 & 1 & 0 & -1 & 0 & 32.7 \\ 0 & 1 & -3 & -1 & 3 & -163.8 \end{array}\right] \quad \boxed{-163.8\,kJ}$$

27 Topic D Problem 27

Given the following chemical reactions and ΔH values:

$$As_2O_5(s) + 3\,H_2O(l) \longrightarrow 2\,H_3AsO_4(s) \qquad \Delta H = -30.2\,kJ$$
$$H_3AsO_4(s) + 3\,KOH(s) \longrightarrow K_3AsO_4(s) + 3\,H_2O(l) \qquad \Delta H = -31.6\,kJ$$
$$2\,KOH(s) \longrightarrow K_2O(s) + H_2O(l) \qquad \Delta H = 202.0\,kJ$$

Calculate ΔH for the chemical reaction below:

$$As_2O_5(s) + 3\,K_2O(s) \longrightarrow 2\,K_3AsO_4(s)$$

27.1 Solution

Matrix form

$$\begin{array}{ccccccc} As_2O_5 & H_3AsO_4 & KOH & H_2O & K_2O & K_3AsO_4 & \Delta H \end{array}$$

$$\left[\begin{array}{cccccc|c} -1 & 2 & 0 & -3 & 0 & 0 & -30.2 \\ 0 & -1 & -3 & 3 & 0 & 1 & -31.6 \\ 0 & 0 & -2 & 1 & 1 & 0 & 202.0 \end{array}\right]$$

$$\begin{pmatrix} -1 & 0 & 0 & 0 & -3 & 2 \end{pmatrix} \leftarrow \text{Target}$$

$$\left[\begin{array}{cccccc|c} -1 & 2 & 0 & -3 & 0 & 0 & -30.2 \\ 0 & -1 & -3 & 3 & 0 & 1 & -31.6 \\ 0 & 0 & -2 & 1 & 1 & 0 & 202.0 \end{array}\right] \begin{array}{c} \\ \times 2 \\ \times(-3) \end{array} \longrightarrow \left[\begin{array}{cccccc|c} -1 & 2 & 0 & -3 & 0 & 0 & -30.2 \\ 0 & -2 & -6 & 6 & 0 & 2 & -63.2 \\ 0 & 0 & 6 & -3 & -3 & 0 & -606.0 \end{array}\right]$$

$$\xrightarrow{+R_2} \left[\begin{array}{cccccc|c} -1 & 0 & -6 & 3 & 0 & 2 & -93.4 \\ 0 & -2 & -6 & 6 & 0 & 2 & -63.2 \\ 0 & 0 & 6 & -3 & -3 & 0 & -606.0 \end{array}\right] \xrightarrow{+R_3} \left[\begin{array}{cccccc|c} -1 & 0 & 0 & 0 & -3 & 2 & -699.4 \\ 0 & -2 & -6 & 6 & 0 & 2 & -63.2 \\ 0 & 0 & 6 & -3 & -3 & 0 & -606.0 \end{array}\right]$$

$$\Delta H = \boxed{-699.4\ kJ}$$

28 Topic D Problem 28

The enthalpy of fusion (ΔH_f°) of solid $AgNO_3$ is -124 kJ/mol.

a) Based on this information, write a balanced chemical equation for which ΔH = -124 kJ. Include the state of each substance in your equation.

b) Write a balanced chemical equation for which ΔH = 124 kJ.

c) Write a balanced chemical equation for which ΔH = -62 kJ. Hint: 124 = 2 $\times$62.

28.1 Solution

a/ $Ag(s) + \frac{1}{2}N_2(g) + \frac{3}{2}O_2(g) \longrightarrow AgNO_3(s)$, $\Delta H = -124\,kJ$

b/ $AgNO_3(s) \longrightarrow Ag(s) + \frac{1}{2}N_2(g) + \frac{3}{2}O_2(g)$, $\Delta H = 124\,kJ$

c/ $\frac{1}{2}Ag(s) + \frac{1}{4}N_2(g) + \frac{3}{4}O_2(g) \longrightarrow \frac{1}{2}AgNO_3(s)$, $\Delta H = -62\,kJ$

29 Topic D Problem 29

The enthalpy of formation of solid AgBr is -100.4 kJ. Based on this information, can you calculate ΔH for the reaction $Ag^{+}(aq) + Br^{-}(aq) \longrightarrow AgBr(s)$? Explain why or why not.

29.1 Solution

ΔH is not calculatable. The equation given includes more energy than just that of the formation of the AgBr(s). It also includes the energy to ionize both the Ag and the Br, both of which are in a table but neither of which is included in the problem.

30 Topic D Problem 30

Calculate the volume of gaseous C_4H_{10} (butane) at 25.00°C and 785.0 torr that must be burned in a closed, rigid container if you want to obtain enough heat to convert 15.50 g of ice at 0.00°C into steam at 100.00°C. Use the following information:
ΔH_f° of C_4H_{10}(g) = -149.1 kJ/mol
ΔH_f° of H_2O(l) = -285.8 kJ/mol
ΔH_f° of CO_2(g) = -393.5 kJ/mol
ΔH_{fusion} of ice = 6.009 kJ/mol
$\Delta H_{vaporization}$ of water = 40.67 kJ/mol at 100°C
Average specific heat capacity of liquid water in the range 0°C to 100°C = 4.174 $\frac{J}{g \cdot °C}$. Do not look up any other thermochemical information.

30.1 Solution

First find moles of ice/water/steam.

$$MM(H_2O) = 18.016 \text{ g/mol}$$

$$n = \frac{m}{MM} = \frac{15.50 \text{ g}}{18.016 \text{ g/mol}} = 0.860346 \text{ mol}$$

Find heat req'd to go from 0° ice to 100° steam

$$Q = (6.009 \text{ kJ/mol})(0.860346 \text{ mol}) + (4.174 \tfrac{J}{g \cdot °C})(15.50 \text{ g})(100°C) + (40.67 \text{ kJ/mol})(0.860346 \text{ mol})$$

$$= 5.1698 \text{ kJ} + 6.4697 \text{ kJ} + 34.9903 \text{ kJ} = 46.6298 \text{ kJ}$$

Find ΔH for the butane burning.

$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 10H_2O(\ell) + 8CO_2(g)$$

$$4C(s) + 5H_2(g) \rightarrow C_4H_{10}(g),\ \Delta H = -149.1 \text{ kJ}$$

$$H_2(g) + \tfrac{1}{2}O_2(g) \rightarrow H_2O(\ell),\ \Delta H = -285.8 \text{ kJ}$$

$$C(s) + O_2(g) \rightarrow CO_2(g),\ \Delta H = -393.5 \text{ kJ}$$

$$\begin{array}{ccccccc} C_4H_{10} & C & H_2 & O_2 & H_2O & CO_2 & \Delta H \end{array}$$

$$\left[\begin{array}{cccccc|c} 1 & -4 & -5 & 0 & 0 & 0 & -149.1 \\ 0 & 0 & -1 & -\frac{1}{2} & 1 & 0 & -285.8 \\ 0 & -1 & 0 & -1 & 0 & 1 & -393.5 \end{array}\right]$$

$$(-2 \quad 0 \quad 0 \quad -13 \quad 10 \quad 8) \leftarrow \text{Target}$$

$$\left[\begin{array}{cccccc|c} 1 & -4 & -5 & 0 & 0 & 0 & -149.1 \\ 0 & 0 & -1 & -\frac{1}{2} & 1 & 0 & -285.8 \\ 0 & -1 & 0 & -1 & 0 & 1 & -393.5 \end{array}\right] \begin{array}{c} \times(-2) \\ \times 10 \\ \times 8 \end{array} \left[\begin{array}{cccccc|c} -2 & 8 & 10 & 0 & 0 & 0 & 298.2 \\ 0 & 0 & -10 & -5 & 10 & 0 & -2858 \\ 0 & -8 & 0 & -8 & 0 & 8 & -3148 \end{array}\right]$$

$$\xrightarrow{+R_2+R_3} \left[\begin{array}{cccccc|c} -2 & 0 & 0 & -13 & 10 & 8 & -5707.8 \\ 0 & 0 & -10 & -5 & 10 & 0 & -2858 \\ 0 & -8 & 0 & -8 & 0 & 8 & -3148 \end{array}\right] \quad \Delta H = -5707.8 \text{ kJ}$$

At this point, since the container is of constant volume, we use ΔE, not ΔH, the former of which we should find now. In our equation, we can see that $\Delta \mathrm{n}_{\mathrm{gas}} = -7\,\mathrm{mol}$.

$$\begin{align}
\Delta \mathrm{H} &= \Delta \mathrm{E} + \mathrm{RT}\,\Delta \mathrm{n}_{\mathrm{gas}} \tag{15}\\
\Delta E &= \Delta \mathrm{H} - \mathrm{RT}\,\Delta \mathrm{n}_{\mathrm{gas}} \tag{16}\\
&= -5707.8\,\mathrm{kJ} - (8.314\,\frac{\mathrm{J}}{\mathrm{mol\,K}})(298.15\mathrm{K})(-7\,\mathrm{mol}) \tag{17}\\
&= -5707.8\,\mathrm{kJ} + 17.4\,\mathrm{kJ} = -5690.4\,\mathrm{kJ} \tag{18}
\end{align}$$

From here, we use our favorite ratio.

$$n_{\mathrm{sp}} = \frac{n\,\Delta E_{\mathrm{sp}}}{\Delta E} = \frac{(2\,\mathrm{mol}) \times (-\underline{46.62}98\,\mathrm{kJ})}{-5690.4\,\mathrm{kJ}} = 0.0\underline{1638}88\,\mathrm{mol} \tag{19}$$

Lastly, we use the Ideal Gas Law.

$$\begin{align}
PV &= nRT \tag{20}\\
V &= \frac{n_{\mathrm{sp}}RT}{P} = \frac{(0.0\underline{1638}88\,\mathrm{mol})(62.36\,\frac{\mathrm{torr\,L}}{\mathrm{mol\,K}})(298.15\mathrm{K})}{785.0\,\mathrm{torr}} \tag{21}\\
&= 0.\underline{3881}6675\,\mathrm{L} = \boxed{388.2\,\mathrm{mL}} \tag{22}
\end{align}$$

1 Topic E Problem 1

Calculate the following properties of light that has a wavelength of 490 nm.

a) The frequency

b) The energy of one photon, in joules

c) The photon energy in kJ/mol

d) The number of moles of photons required to supply 10.0 kJ of energy

e) The total energy of 0.0125 moles of photons

f) The number of individual photons required to supply 25.0 J of energy.

1.1 Solution

E.1)

a/ $c = \lambda\nu \rightarrow \nu = \frac{c}{\lambda} = \frac{2.998E8 \text{ m/s}}{490E-9 \text{ m}} = \boxed{6.12E14 \text{ Hz}}$

b/ $E = h\nu = (6.626E-34 \text{ J}\cdot\text{s})(6.118E14 \text{ Hz}) = 4.054E-19 \text{ J} = \boxed{4.05E-19 \text{ J}}$

c/ $4.054E-19 \text{ J} \times \frac{6.022E23}{1 \text{ mol}} = 244.134 \text{ kJ/mol} = \boxed{244 \text{ kJ/mol}} = ME$

d/ $\frac{10.0 \text{ kJ}}{244.134 \text{ kJ/mol}} = 0.04096 \text{ mol} = \boxed{0.0410 \text{ mol}}$

e/ $ME \times n = 244.134 \text{ kJ/mol} \times 0.0125 \text{ mol} = 3.05167 \text{ kJ} = \boxed{3.05 \text{ kJ}}$

f/ $\frac{E_{req'd}}{E_{individual}} = \frac{25.0 \text{ J}}{4.05E-19 \text{ J}} = 6.1667E19 = \boxed{6.17 \times 10^{19}}$

2 Topic E Problem 2

Frequencies of FM radio stations are usually given in megahertz (MHz), where 1 MHz equals 106 $\sec^{-1}$. For a radio station that broadcasts at 94.3 MHz, calculate the following:

a) The frequency in $\sec^{-1}$

b) The wavelength of the radiation, in meters

c) The wavelength of the radiation, in nanometers

d) The photon energy, in joules

e) The photon energy, in kJ/mol

2.1 Solution

a/ $\nu = 94.3\ \text{MHz} = \boxed{94.3 \times 10^{6}\ \sec^{-1}}$

b/ $c = \lambda\nu \rightarrow \lambda = \dfrac{c}{\nu} = \dfrac{2.998E8\ \text{m/s}}{94.3E6\ \text{s}^{-1}} = 3.179\ \text{m} = \boxed{3.18\ \text{m}}$

c/ $\lambda = \boxed{3.18 \times 10^{9}\ \text{nm}}$

d/ $E = h\nu = (6.626E{-34}\ \text{J}\cdot\text{s})(94.3E6\ \text{s}^{-1}) = 6.248318E{-26}\ \text{J} = \boxed{6.25E{-26}\ \text{J}}$

e/ $ME = E \times N_A = (6.248318E{-26}\ \text{J})(6.022E23\ \text{mol}^{-1}) = 0.37627\ \text{J/mol} = \boxed{0.376}$

The answer to part (e) is 0.376 J/mol if you have trouble reading it.

3 Topic E Problem 3

Molecular bromine (Br_2) breaks apart into bromine atoms if it is exposed to light whose energy is 190 kJ/mol.

a) Calculate the wavelength of this light, in nanometers.

b) Does this light fall in the visible spectrum? If not, does it fall in the infrared region, or in the ultraviolet region?

3.1 Solution (a)

Here, ME refers to the molar energy, meaning the amount of energy per mole.

$$E = \frac{ME}{N_A} = \frac{190 \times 10^3 \,\text{kJ/mol}}{6.022 \times 10^{23}\,\text{mol}^{-1}} = \underline{3.15}5 \times 10^{-19}\,\text{J} \tag{23}$$

$$E = h\nu \tag{24}$$

$$\nu = \frac{E}{h} = \frac{\underline{3.15}5 \times 10^{-19}\,\text{J}}{6.626 \times 10^{-34}\,\text{J} \cdot \text{s}} = \underline{4.76}169 \times 10^{14}\,\text{Hz} \tag{25}$$

$$\lambda = \frac{\text{c}}{\nu} = \frac{2.998 \times 10^{8}\,\text{m/s}}{\underline{4.76}169 \times 10^{14}\,\text{Hz}} = \underline{6.29}60796 \times 10^{-7}\,\text{m} \tag{26}$$

$$= \underline{629}.60796\,\text{nm} = \boxed{630\,\text{nm}} \tag{27}$$

3.2 Solution (b)

This <u>does</u> fall in the visible spectrum. The visible spectrum runs from about 400 nm to 700 nm.

4 Topic E Problem 4

When an atom absorbs light, does an electron in the atom move from a lower energy level to a higher energy level, or does it move from a higher level to a lower level?

4.1 Solution

Absorbing causes it to move from a lower level to a higher level.

5 Topic E Problem 5

Here are two of the allowed energy levels for a lithium atom:

Level 2: -8.638×10^{-19} J; Level 3: -5.678×10^{-19} J

a) What is ΔE for a lithium atom when an electron moves from level 3 to level 2? Give your answer in joules.

b) What is ΔE for a lithium atom when an electron moves from level 2 to level 3? Give your answer in joules.

c) Convert your answer to part a into kJ/mol.

d) When the electron drops from level 3 to level 2, the atom emits a photon. Calculate the wavelength of this photon, in nanometers.

e) Can visible light move an electron from level 2 to level 3? Explain your answer.

5.1 Solution (a)

$$\Delta E = E_2 - E_3 = -8.638 \times 10^{-19}\,\mathrm{J} + 5.678 \times 10^{-19}\,\mathrm{J} = \boxed{-2.960 \times 10^{-19}\,\mathrm{J}}$$

5.2 Solution (b)

$$\Delta E = E_3 - E_2 = -5.678 \times 10^{-19}\,\mathrm{J} + 8.638 \times 10^{-19}\,\mathrm{J} = \boxed{2.960 \times 10^{-19}\,\mathrm{J}}$$

5.3 Solution (c)

$$ME = E \times N_A = -2.960 \times 10^{-19}\,\mathrm{J} \times 6.022 \times 10^{23}\,\mathrm{mol}^{-1} \tag{28}$$

$$= -\underline{17.82}512 \times 10^{4}\,\mathrm{J/mol} = \boxed{-178.3\,\mathrm{kJ/mol}} \tag{29}$$

5.4 Solution (d)

The energy of the photon would be the negative of the energy lost when jumping from level 3 to level 2.

$$E = h\nu = \frac{hc}{\lambda} \tag{30}$$

$$\lambda = \frac{hc}{E} = \frac{(6.626 \times 10^{-34}\,\mathrm{J \cdot s})(2.998 \times 10^{8}\,\mathrm{m/s})}{2.960 \times 10^{-19}\,\mathrm{J}} \tag{31}$$

$$= 6.711 \times 10^{-7}\,\mathrm{m} = \boxed{671.1\,\mathrm{nm}} \tag{32}$$

5.5 Solution (e)

Visible light ranging from 400nm to 700nm, it could, so the answer is yes. It would be on the edge of the spectrum, though, so some people might not be able to see it.

6 Topic E Problem 6

An atom can only undergo one electron transition at a time. However, when we observe the emission spectrum of an element, we see many lines. Explain.

6.1 Solution

When we observe the emission spectrum of an element, we are often observing the emission spectrum of many different atoms of that element and not just one. One atom may absorb the wavelength for one color, while another atom may absorb the wavelength for another color. The emission spectrum we see (such as on a spectrometer) is merely the total of all of these emitted colors. We can think of it less as a spectrum and more as a statistical graph of the total number of data points at specific values being represented by the presence and boldness of a spectrum line at that wavelength.

7 Topic E Problem 7

Here are three of the allowed energy levels for a calcium atom:

Level A: -710.3 kJ/mol; Level B: -648.4 kJ/mol; Level C: -514.2 kJ/mol

Calculate the wavelengths of the three emission lines that can be produced by electron transitions involving these levels, and list the initial and final level for each emission line.

7.1 Solution A and B

Going from B to A would be the direction in which the electron lowers in energy and releases a photon. Wavelength is calculatable from energy, whch is itself calculatable from molar energy.

$$E = \frac{hc}{\lambda}; ME = E * N_A \tag{33}$$

$$\begin{aligned}
\Delta ME &= ME_B - ME_A = -648.4\,\text{kJ/mol} + 710.3\,\text{kJ/mol} && (34)\\
&= 61.9 \times 10^3\ \text{J/mol} && (35)\\
\lambda &= \frac{hc}{E} = \frac{hcN_A}{ME} && (36)\\
&= \frac{(6.626 \times 10^{-34}\,\text{J}\cdot\text{s})(2.998 \times 10^8\,\text{m/s})(6.022 \times 10^{23}\,\text{mol}^{-1})}{61.9 \times 10^3\ \text{J/mol}} && (37)\\
&= \frac{0.\underline{1196}255\,\text{m}}{61.9 \times 10^3} = \underline{1.932}56 \times 10^{-6}\ \text{m} = \boxed{1.933 \times 10^{-6}\ \text{m}} && (38)
\end{aligned}$$

7.2 Solution B and C

It would go from C to B to release a photon.

$$\begin{aligned}
\Delta ME &= ME_C - ME_B = -514.2\,\text{kJ/mol} + 648.4\,\text{kJ/mol} && (39)\\
&= 134.2 \times 10^3\ \text{J/mol} && (40)\\
\lambda &= \frac{hc}{E} = \frac{hcN_A}{ME} && (41)\\
&= \frac{(6.626 \times 10^{-34}\,\text{J}\cdot\text{s})(2.998 \times 10^8\,\text{m/s})(6.022 \times 10^{23}\,\text{mol}^{-1})}{134.2 \times 10^3\ \text{J/mol}} && (42)\\
&= \frac{0.\underline{1196}255\,\text{m}}{134.2 \times 10^3} = \underline{8.913}97 \times 10^{-7}\ \text{m} = \boxed{8.914 \times 10^{-7}\ \text{m}} && (43)
\end{aligned}$$

7.3 Solution A and C

It would go from C to A to release a photon.

$$\Delta ME = ME_C - ME_A = -514.2\,\text{kJ/mol} + 710.3\,\text{kJ/mol} \tag{44}$$

$$= 196.1 \times 10^3\ \text{J/mol} \tag{45}$$

$$\lambda = \frac{hc}{E} = \frac{hcN_A}{ME} \tag{46}$$

$$= \frac{(6.626 \times 10^{-34}\ \text{J} \cdot \text{s})(2.998 \times 10^8\ \text{m/s})(6.022 \times 10^{23}\ \text{mol}^{-1})}{196.1 \times 10^3\ \text{J/mol}} \tag{47}$$

$$= \frac{0.\underline{1196}255\,\text{m}}{196.1 \times 10^3} = \underline{6.100}23 \times 10^{-7}\ \text{m} = \boxed{6.100 \times 10^{-7}\ \text{m}} \tag{48}$$

8 Topic E Problem 8

A line in the emission spectrum of neon has a wavelength of 471.5 nm. The final energy level for the corresponding electron transition is -266.7 kJ/mol. What is the initial energy level for this transition?

8.1 Solution

The wavelength of the line correspond to the change in the energy from the initial to the final wavelength. Since this is an emission of light rather than an absorption, the change in energy will be have to be negative.

$$\Delta ME = -N_A * \frac{hc}{\lambda} \tag{49}$$

$$= -\frac{(6.626 \times 10^{-34}\,\mathrm{J \cdot s})(2.998 \times 10^{8}\,\mathrm{m/s})(6.022 \times 10^{23}\,\mathrm{mol^{-1}})}{471.5 \times 10^{-9}\,\mathrm{m}} \tag{50}$$

$$= -\frac{0.\underline{1196}255}{471.5 \times 10^{-9}}\,\mathrm{J/mol} = -\underline{253.7}126\,\mathrm{kJ/mol} \tag{51}$$

$$ME_i = ME_f - \Delta ME = -266.7\,\mathrm{kJ/mol} + \underline{253.7}126\,\mathrm{kJ/mol} \tag{52}$$

$$= -\underline{13.0}126\,\mathrm{kJ/mol} = \boxed{-13.0\,\mathrm{kJ/mol}} \tag{53}$$

9 Topic E Problem 9

The following electronic transitions and the corresponding wavelengths can be seen in the emission spectrum of potassium:

level 7 $\rightarrow$ level 6	wavelength = 770.1 nm
level 8 $\rightarrow$ level 7	wavelength = 1243.6 nm
level 10 $\rightarrow$ level 8	wavelength = 14,818.5 nm

Using this information, calculate the wavelength that corresponds to the level 10 $\rightarrow$ level 6 transition in a potassium atom.

9.1 Solution

This is a four-step process. Step one: convert wavelength to energy. I will keep Planck's constant and the speed of light as constants for the time being.

$$E_{7,6} = \frac{hc}{770.1\,\text{nm}} \tag{54}$$

$$E_{8,7} = \frac{hc}{1243.6\,\text{nm}} \tag{55}$$

$$E_{10,8} = \frac{hc}{14818.5\,\text{nm}} \tag{56}$$

Step two: add the three energies together to get the energy required to go from level 10 to level 6. We can also pull out the hc since it's a constant in all three.

$$E_{10,6} = E_{10,8} + E_{8,7} + E_{7,6} \tag{57}$$

$$= \frac{hc}{14818.5\,\text{nm}} + \frac{hc}{1243.6\,\text{nm}} + \frac{hc}{770.1\,\text{nm}} \tag{58}$$

$$= hc\left(\frac{1}{14818.5\,\text{nm}} + \frac{1}{1243.6\,\text{nm}} + \frac{1}{770.1\,\text{nm}}\right) \tag{59}$$

Step three: since $E = \frac{hc}{\lambda}$, we can divide both sides by hc to find the reciprocal of the wavelength.

$$\frac{E_{10,6}}{hc} = \frac{1}{\lambda_{10,6}} = \frac{1}{14818.5\,\text{nm}} + \frac{1}{1243.6\,\text{nm}} + \frac{1}{770.1\,\text{nm}} \tag{60}$$

Step four: Take the reciprocal to get the final answer.

$$\lambda_{10,6} = \left(\frac{1}{14818.5\,\text{nm}} + \frac{1}{1243.6\,\text{nm}} + \frac{1}{770.1\,\text{nm}}\right)^{-1} = \boxed{460.8\,\text{nm}} \tag{61}$$

For anyone interested in the more math-physics behind this, this does set up an equation for the equivalent wavelength for multiple emitted or absorbed wavelengths.

$$\lambda_{\text{eq}} = \left(\sum \lambda_i^{-1}\right)^{-1} \tag{62}$$

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