**Exercise 7:** **Heat Balance**

The exercise is conducted using the Virtual Lab program and a spreadsheet. The online version of the application is available on the website:

<http://chemcollective.org/vlab/vlab.php>

The data obtained in the Virtual Lab program and the calculated values should be recorded in the appropriate tables under the 'ex7' tab in the spreadsheet "Physical Chemistry ".

**I. Problem 1**

To launch the relevant task, select the following tabs:

***File → Load an Assignment → Thermochemistry → Coffee***

Using the Virtual Lab application, prepare coffee with milk with a temperature of 90°C, given 250 ml of coffee from an espresso machine at 95°C and milk with a temperature of 10°C. Determine the total volume of milk that needs to be added to the coffee, knowing that the heat capacity of both coffee and milk is 4.18 J/(g∙K), and their densities are approximately 1 g/ml.

**1. Calculating the required amount of milk.**  
We use the heat balance, which states that:

**heat lost = heat gained  
(heat of the coffee) = (heat of the milk)**

Heat is denoted by the letter Q, so the above relationship takes the form:

**QCOFFEE = QMILK**

We will use the following formula for heat:

**Q = m ∙ Cw ∙ ∆T**

cw – heat capacity (specific heat): 4.18 J/(g∙K)

m– mass

∆T – temperature difference

If we write the equation QCOFFEE = QMILK, substituting the appropriate symbols from the equation above, we obtain the following equation:

**mCOFFEE ∙ CCOFFEE ∙ ∆TCOFFEE = mMILK ∙ CMILK ∙ ∆TMILK**

From the above equation, we need to determine the mass of the milk that should be added to the coffee. The only unknown is the amount of milk (mMILK), while the other quantities are known. The mass of the coffee is provided in the problem description (known volume and density), as well as the values of the heat capacity for both coffee and milk (for simplicity, both equal to the heat capacity of water). We need to calculate the temperature difference for the coffee and milk. The initial temperature of the coffee is 95°C, and that of the milk is 10°C, while after mixing, the temperature should be 90°C.

The temperature difference should be calculated using the formula:  
**∆T = Tfinal – Tinitial**

The initial temperatures of the milk and coffee are known, while the final temperature is common for both substances. In the heat balance formula, we should use the absolute values of the temperature differences (ignoring the negative sign).

Having all the data, we can determine the mass of the milk (m**MILK**) from the appropriate equation. Since the density of the milk is assumed to be equal to 1 g/ml, the mass of the milk is equal to its volume.

**2. Conduct the appropriate reactions in the Virtual Lab program to ensure the accuracy of the calculations.**  
Pour 250 cm³ of coffee into a beaker with a capacity of 600 cm³. Change the temperature of the beaker with coffee to 95°C, ensuring that it is insulated. Change the temperature of the milk in the flask to 10°C. Add the previously calculated amount of milk to the beaker with coffee. The temperature in the beaker should change to 90°C.

**Report**  
Organise the collected data in Table 1 and the calculated values in Table 2. Present the calculations and provide conclusions.

**II. Problem 2**

To launch the relevant task, select the following tabs:

***File → Load Assignment → Thermochemistry → Coolant I***

Substance Y is a coolant. Determine whether this substance will be more efficient than ethylene glycol. Using the VLab program, generate data that will allow you to determine the heat capacity of the experimental refrigerant. Compare the obtained values with the heat capacity of glycol, which is 2.2 J/(g∙K). [Note: The density of substance Y is 2.78 g/ml; the heat capacity of water is 4.18 J/(g∙K).]

It is necessary to determine the heat capacity of substance Y and compare it with the heat capacity of glycol. We will once again use the heat balance by mixing substance Y with water:

**heat lost = heat gained**

**QY = QWATER**

We will mix 40 ml of water at a temperature of 50°C with 10 ml of substance Y at a temperature of 25°C. Using the known formula for heat (Q = m ∙ Cw ∙ ∆T), we obtain the following relationship:

**mY ∙ CY ∙ ∆TY = mWATER ∙ CWATER ∙ ∆TWATER**

The masses of water and substance Y are known, as well as the heat capacity of water (4.18 J/(g∙K)). To determine the heat capacity of substance Y, it is essential to calculate the temperature difference between water and substance Y. Their initial temperatures are known (50°C and 25°C, respectively), but we need to determine their final temperature.

To do this, we will mix the appropriate amounts of water and substance Y at their respective temperatures and read the final temperature. For this purpose, pour 40 ml of water into a beaker with a capacity of 250 cm³, set the beaker temperature to 50°C, and insulate it. Next, add 10 ml of substance Y (which initially has a temperature of 25°C) to this beaker and read the final temperature. Knowing the final temperature allows us to calculate the temperature difference for substance Y and water, similarly to Problem 1. In the heat balance formula, we should use the absolute values of the temperature differences (ignoring the negative sign).

With all the data, we can determine the heat capacity of substance Y (CY) using the appropriate formula. It is important to remember that the density of substance Y is 2.78 g/ml and the density of water is 1 g/ml, which affects the mass value in the formula.

Compare the determined value of the heat capacity of substance Y with the heat capacity of glycol, and then indicate and justify which of these two substances is a better coolant.

**Report**  
Organise the collected data in Table 3 and the calculated values in Table 4. Present the calculations and provide conclusions.

**III. Problem 3**

To launch the relevant task, select the following tabs:

***File → Load Assignment → Solubility and Solids → Temperature and the Solubility of Salts***

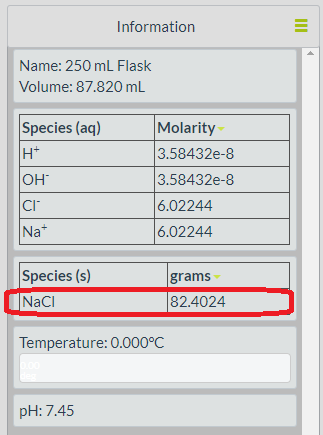
**a) Based on the reagents provided in the task, plot the solubility curves for the following salts: NaCl, NaNO3, and Ce2(SO4)3 over a temperature range of 0 to 90°C (at intervals of 10°C). Based on the obtained values, determine the energetic characteristics of the processes involved.**

**b) Using the provided reagents, determine the molar heat of dissolution for the attached salts and rank them according to increasing exothermic character.**

**c)** Based on the data collected in points **a** and **b**, determine the amount of any chosen salts the dissolution of which in 100 ml of water will cause the following temperature changes in the solution:

* 50°C → 47°C
* 1°C → 5.5°C

**3a. Determining the solubility of salts over a temperature range of 0 to 90°C (at intervals of 10°C).**

Pour 50 ml of water into a 250 cm³ beaker and insulate the beaker. Next, add 100 g of NaCl to the beaker and set its temperature to 0°C. From the panel on the right, read the amount of undissolved NaCl (in this case, it is 82.4024 g). Then, change the temperature of the beaker to 10°C and again read the amount of undissolved salt, and continue to change the temperature in increments of 10°C, recording the relevant data. This procedure should be repeated for the other two salts in separate beakers.  
The solubility of the salts should be calculated using the formula:

**Solubility = (100 - x) g / 50 ml**  
where **x** is the amount of undissolved salt, as read from the program.

For the three tested salts, solubility versus temperature graphs should be plotted

**3b. Determination of the heat of dissolution of salts.**

Pour 100 ml of water into a 250 cm³ beaker and insulate the beaker. Then, add 1 g of NaCl to the beaker and record the final temperature. The heat of dissolution of the salt should be determined using the formula:

**Q = m ∙ Cw ∙ ∆T**

cw – specific heat capacity: 4.18 J/(g∙K)

m– mass (assumed to be 100 g)

∆T – temperature difference

The temperature difference should be calculated by subtracting the initial temperature (25°C) from the final temperature, taking the sign into account. **NOTE:** Temperature should be recorded with an accuracy of 0.01°C

**3c. Changing the temperature of water using salt addition.**

In the case of increasing the water temperature from 1°C to 5.5°C, cerium sulfate should be selected, as it is the only available salt that enables such a process.

First, it is necessary to calculate how much heat must be supplied to 100 ml of water for this process to occur. Once again, the following formula should be used:

**Q = m ∙ Cw ∙ ∆T**

The mass of the water and its heat capacity are known, while the temperature difference is 4.5°C (5.5°C - 1°C). With all the data available, the amount of heat that needs to be supplied should be calculated. From the previous exercise, the amount of heat required for the dissolution of 1 g of Ce₂(SO₄)₃ is known. Therefore, the following proportion can be set up:

**1 g - Q (heat per 1 g calculated in point 3b for cerium sulfate**

**X g - amount of heat that must be supplied to the sample, calculated previously**

From the above proportion, the value of **X**, representing the amount of cerium sulfate that needs to be added to the water to increase its temperature from 1°C to 5.5°C, should be determined.

In the Virtual Lab program, pour 100 ml of water into a 250 cm³ beaker, change its temperature to 1°C while insulating the beaker, and then add the previously calculated amount (X) of cerium sulfate. The temperature in the beaker should rise to 5.5°C.

In the second case (lowering the temperature from 50°C to 47°C), any of the remaining salts can be chosen, and the above calculations should be repeated by substituting the appropriate values. Note that the temperature difference in this case is 3°C (absolute value, ignoring the negative sign).

**Report**  
Collected data and calculated values should be compiled in Tables 5, 6, and 7, corresponding to points 3a, 3b, and 3c, respectively. For points 3a and 3b, example calculations should be presented, while for point 3c, complete calculations should be provided along with conclusions for all subpoints. In point 3a, graphs showing the solubility of the tested salts as a function of temperature should also be plotted.