Experimental Problem

This experimental problem consists of two related parts.

Part 1
Measurement of the specific heat of aluminum in the 45^0 C – 65^0 C temperature range. (10 points)

In this part, you can use the following equipment ONLY:

1. A plastic cup with a cap which has a hole for the thermometer;
2. A digital thermometer with accuracy of 0.1^0C; The temperature of the **sensor (10)** is shown on the top display, and bottom display shows the temperature of the room. Do not press max/min button: pressing max/min button changes the readings between current, maximal and minimal values. If water temperature exceeds 70°C, the thermometer shows "H" denoting it is out of its range. **WARNING: DO NOT USE THE THERMOMETER TO MEASURE THE TEMPERATURE OF LIQUID NITROGEN! THERMOMETER CAN BE USED ONLY IN PART 1.**
3. An aluminum cylinder with a hole;
4. Electronic scales with accuracy of 1g; Make sure that the scales are situated on the flat surface. The button Tare/Zero serves as On/Off and sets the zero reading of the scales. Do not press any other buttons. Note: the scales automatically turn OFF after some time; you have to turn them ON back and reset the zero reading of the scales. Press the top of the

scales approximately every 50 seconds in order to prevent automatic switch off of the scales.

5. A digital timer; Pressing left button shifts the timer from Clock mode to Stopwatch mode. In Stopwatch mode the middle button serves as Stop/Start, and the right button serves as Reset.
6. Dewar flask with hot water;
7. A jar for the used water;
8. Plotting (graphing) paper (2 pages);
9. Pieces of thread.

The results of the measurement of specific heat of aluminum will be used in Part 2 of the experimental problem.

The specific heat of aluminum should be determined from the comparison of two experimental curves:

1) the cooling curve of hot water in a plastic cup without the aluminum cylinder (the first experiment);
2) the cooling curve of hot water in a plastic cup with aluminum cylinder immersed (the second experiment);

The specific heat of water is given $c_w = 4.20 kJ/(kg\,K)$.

Density of water $\rho_w = 1.00 \cdot 10^3 kg/m^3$.

Density of aluminum $\rho_{Al} = 2.70 \cdot 10^3 kg/m^3$.

<u>Warning:</u> Be very careful with hot water. Remember that water at temperature $T>50^0$ C can cause burns. DO NOT USE LIQUID NITROGEN IN THIS PART!

The task

1a) **[1 point]** Derive theoretically an expression for aluminum specific heat c_{Al} in terms of experimentally measured quantities : mass m_1 of hot water in the first experiment, mass m_2 of hot water in the second experiment, mass m of aluminum cylinder and the ratio of heat capacities $K = C_1/C_2$, where C_1 is the heat capacity of water in the first experiment, C_2 is the combined heat capacity of water and aluminum cylinder in the second experiment.

In parts 1b) and 1c) you will perform measurements to determine K. Parts 1b) and 1c) should be performed with closed caps. Assume that in this case heat exchange of the contents of the cup with the environment depends linearly on the difference in their temperatures. The linearity coefficient depends only on the level of the water in the cup. Make sure that the aluminum cylinder is fully immersed into water in part 1c). You can neglect the heat capacity of the cup.

1b) **[1.5 points]** Perform the first experiment – investigate the relationship between the temperature of water T_1 and time t in the range of temperatures from 45^0C to 65^0C. Provide a table of measurements. Write the value of m_1 on the answer sheet.

1c) **[1.5 points]** Perform the second experiment – investigate the relationship between the temperature of water with aluminum cylinder T_2 and time t in the range of temperatures from 45^0C to 65^0C. Provide a table of measurements. Write the values of m_2 and m on the answer sheet.

1d) **[4 points]** Use graphs to determine the ratio of the heat capacities $K = C_1 / C_2$ and the uncertainty ΔK. Write the values of K and ΔK on the answer sheet.

1e) **[2 points]** Determine the numerical value of c_{Al} and estimate the uncertainty of measurement Δc_{Al}. Write the values of c_{Al} and Δc_{Al} on the answer sheet.

Part 2

Measurement of the specific latent heat of evaporation of liquid nitrogen. (10 points)

In this part you can use the following equipment:

1. A Styrofoam cup with a cap;
2. Dewar flask with liquid nitrogen;
3. An aluminum cylinder with a hole (item 3, Part 1);
4. Electronic scales with accuracy of 1g (item 4, Part 1);
5. A digital timer (item 5, Part 1);
6. Plotting (graphing) paper (2 pages);
7. Pieces of thread.

The specific latent heat of evaporation of water is well known, while rarely we have to deal with one the main atmospheric gases, nitrogen, in its liquid form. The boiling temperature of liquid nitrogen under normal atmospheric pressure is very low, $T_N = 77K = -196^0 C$.

In this experiment you are asked to measure the specific latent heat of evaporation of nitrogen. Because of heat exchange with the environment nitrogen in a Styrofoam cup evaporates and its mass decreases at some rate. When an aluminum cylinder initially at room temperature is immersed into nitrogen, nitrogen will boil violently until the temperature of the aluminum sample reaches the temperature of liquid nitrogen. The final brief ejection of some amount of vaporized nitrogen from the cup indicates that aluminum has stopped cooling-- this ejection is caused by the disappearance of the vapor layer between aluminum and nitrogen. After aluminum reaches the temperature of nitrogen, the evaporation of nitrogen will continue.

When considering a wide range of temperatures, one can observe that the specific heat of aluminum c_{Al} depends on absolute temperature. The graph of aluminum's specific heat in arbitrary units versus temperature is shown in Fig. 1. Use the result of specific heat measurement in 45^0C-65^0C temperature range in Part 1 to normalize this curve in absolute units.

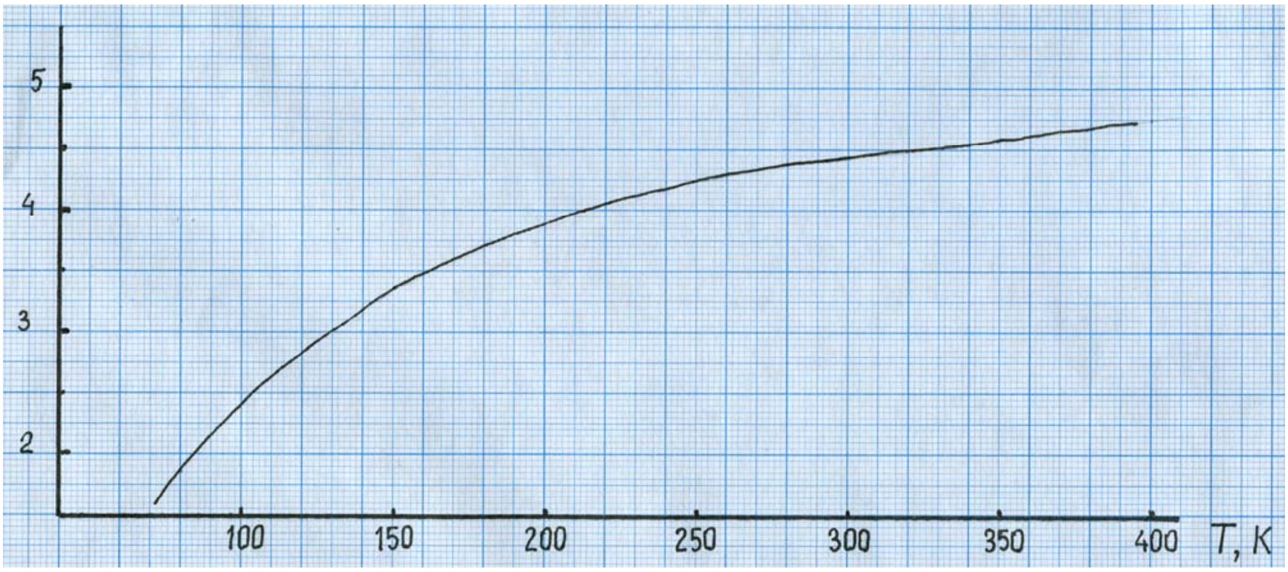

Fig. 1. The relationship between aluminum's specific heat in arbitrary units and temperature.

Warnings:

1) **Liquid nitrogen has temperature $T_N = - 196^oC$. To prevent frostbite do not touch nitrogen or items which were in contact with nitrogen. Make sure to keep away your personal metal belongings such as jewelry, wrist watch, etc.**
2) **Do not put any irrelevant items into nitrogen;**
3) **Be careful while putting the aluminum cylinder into the liquid nitrogen to prevent spurts or spilling.**

The task

2a) **[3 points]** Measure the evaporation rate of nitrogen in a Styrofoam cup with a closed cap, and measure the mass of nitrogen evaporated during the cooling of the aluminum cylinder (aluminum cylinder is loaded through a hole in the cup).

Proceed in the following manner. Set up the Styrofoam on the scales, pour about 250g of liquid nitrogen in it, wait about 5 minutes and then start taking measurements. After some amount of nitrogen evaporates, immerse the aluminum cylinder into the cup – this will result in a violent boiling. After aluminum cylinder cools down to the temperature of nitrogen, evaporation calms down. You should continue taking measurements in this regime for about 5 minutes until some additional amount of nitrogen evaporates. During the whole process record the readings of the scales $M(t)$ as a function of time.

IN NO CASE SHOULD YOU TOUCH THE ALUMINUM CYLINDER AFTER IT WAS SUBMERGED INTO LIQUID NITROGEN.

In your report provide a table of $M(t)$ and $m_N(t)$, where $m_N(t)$ is the mass of the evaporated nitrogen.

2b) **[1 point]** Using the results of the measurements of $M(t)$ in 2a), plot the graph of the mass of evaporated nitrogen m_N versus time t. The graph should illustrate all the three stages of the process– the calm periods before and after immersion of aluminum, and the violent boiling of nitrogen.

2c) **[3.0 points]** Determine from the graph the mass m_N^{Al} of nitrogen evaporated only due to heat exchange with the aluminum cylinder, as it is cooled down from room temperature to the temperature of liquid nitrogen. In order to do this you have to take into account the heat exchange with the environment through the cup before, during and after the cooling of aluminum. Write the value of m_N^{Al} and its uncertainty Δm_N^{Al} on the answer sheet.

2d) **[0.5 points]** Using the result of measurement of aluminum's specific heat in the temperature range of 45^0C – 65^0C (Part 1), normalize the graph of the relationship between aluminum's specific heat and temperature from arbitrary to absolute units. On the answer sheet write the value of the coefficient β of conversion from arbitrary units to absolute units:

$$c_{Al}(J/(kg \cdot K)) = \beta \cdot c_{Al}(arb.units)$$

2e) **[2.5 points]** Using the results of measurement of the mass of nitrogen evaporated due to cooling of the aluminum cylinder and the normalized graph of the relationship between specific heat and temperature, determine nitrogen's specific latent heat of evaporation λ. Write the value of λ and its uncertainty $\Delta\lambda$ on the answer sheet.

Good Luck and Look Good!