

Introduction: In completing this laboratory activity the various enthalpies of reactions have been calculated, as well as determining the approximate molar mass of copper metal, the enthalpy of neutralization of HNO_3 and HCl both reacting with NaOH , and finally the enthalpy of solution of an unknown salt. The theories of stoichiometry and calorimetry will allow for the experiment to be conducted and the data to be collected with help of the "Lab quest 2" technology.

Safety Precautions:

1. Wear approved eye protection at all times.
2. Wear proper attire (i.e. pants, lab coat etc.)
3. The acid/base solutions supplied are relatively concentrated. Acids and bases are corrosive. Be Carefull!!!

Procedure: As outlined in the manual.

Materials:

Chemicals:

- Metal sample
- 1.1 M HCl
- 1.1 M HNO_3
- 1.0 M NaOH
- Unknown Salt (A)

Equipment:

- Calorimeter ensemble
- 1 test tube
- Lab Quest 2
- Analytical balance
- Wristwatch with seconds hand
- Hotplate
- 250 and 400mL beaker
- 2-50 mL graduated cylinder
- Coloured pencils, graph paper

Observations:

- No physical observations could be made as the metal was reacting in the calorimeter, however they were made watching the Lab Quest 2 measure the changing temperature of the reaction.
- All observable data was to be concluded from the change in temperature on the Lab Quest 2 screen, as presented in the figures 1-8 (see below)

Part 1: Enthalpy of a Metal (Copper)

1. From your graph, calculate the change in temperature of the water, ($\Delta_{\text{water}} T$)

Trial 1:

$$T_{\text{initial}} = 24.8 \text{ } ^\circ\text{C}$$

$$T_{\text{final}} = 28.6 \text{ } ^\circ\text{C}$$

$$\Delta_{\text{water}} T = T_{\text{final}} - T_{\text{initial}}$$

$$\begin{aligned} \Delta_{\text{water}} T &= (28.6 - 24.8) \text{ } ^\circ\text{C} \\ &= 3.8 \text{ } ^\circ\text{C} \end{aligned}$$

➤ Therefore the change in temperature of the water is 3.8°C .

Trial 2:

$$\Delta_{\text{water}} T = 3.0^\circ\text{C}$$

➤ Therefore the change in temperature of the water is 3.0°C .

2. Using the specific heat capacity of water and the mass of the water, calculate the energy gained by the water.

Trial 1:

c = specific heat capacity

$$c_{\text{H}_2\text{O}} = 4.184 \text{ J/g}^\circ\text{C}$$

$$m_{\text{H}_2\text{O}} = \text{mass}_{\text{foam cup} + \text{H}_2\text{O}} - \text{mass}_{\text{foam cup}}$$

$$= (20.1805\text{g}) - (1.87\text{g})$$

$$= 18.3105\text{g}$$

$$\Delta_{\text{water}} T = 3.8^\circ\text{C}$$

$$q = mc(\Delta T)$$

$$= (18.3105\text{g})(4.184 \text{ J/g}^\circ\text{C})(3.8^\circ\text{C})$$

$$= 291.1223 \text{ J}$$

➤ Therefore the amount of energy gained by the water is 291 J.

Trial 2:

➤ Therefore the amount of energy gained by the water is 230 J.

3. Calculate the change in the temperature of the metal, ($\Delta_{\text{metal}} T$) (T_i of the metal MUST be shown on the graph).

Trial 1:

$$q = mc(\Delta T)$$

$$q_{\text{H}_2\text{O}} = -q_{\text{surroundings}}$$

$$q_{\text{metal}} = - (291.1223 \text{ J})$$

$$= -291.1223 \text{ J}$$

$$m_{\text{copper}} = 13.397 \text{ g}$$

$$c_{\text{copper}} = 0.385 \text{ J/g}^\circ\text{C}$$

$$\Delta T_{\text{copper}} = ?$$

$$\Delta T_{\text{copper}} = q/mc$$

$$\Delta T_{\text{copper}} = (-291.1223 \text{ J}) / (13.397\text{g})(0.385 \text{ J/g}^\circ\text{C})$$

$$\Delta T_{\text{copper}} = -56.4^{\circ}\text{C}$$

➤ Therefore the change in temperature of the metal is -56.4°C .

Trial 2:

➤ Therefore the change in temperature of the metal is -75.5°C .

4. Determine the specific heat capacity of the metal, using the energy gained by the water and the mass of the metal.

Trial 1:

$$C_{\text{copper}} = ?$$

$$M_{\text{copper}} = 13.397 \text{ g}$$

$$\Delta T_{\text{copper}} = -56.4^{\circ}\text{C}$$

$$Q_{\text{copper}} = 291.1223 \text{ J}$$

$$Q = (m)(c)(\Delta T)$$

$$C = q / m\Delta T$$

$$C_{\text{copper}} = (-291.1223 \text{ J}) / (13.397 \text{ g})(-56.4^{\circ}\text{C})$$

$$C_{\text{copper}} = 0.385 \text{ J/g}^{\circ}\text{C}$$

➤ Therefore the specific heat capacity of copper is $0.385 \text{ J/g}^{\circ}\text{C}$

Trial 2:

➤ Therefore the specific heat capacity of copper is $0.385 \text{ J/g}^{\circ}\text{C}$.

5. Approximate the molar mass of the metal using its calculated specific heat capacity.

$$C_{\text{copper}} = 0.385 \text{ J/g}^{\circ}\text{C}$$

$$\text{Molar heat capacity}_{\text{metal}} = 24.94 \text{ J/ (mol)} (^{\circ}\text{C})$$

$$\text{Molar mass}_{\text{copper}} = \text{molar heat capacity} / \text{specific heat capacity}$$

$$\text{Molar mass}_{\text{copper}} = (24.94 \text{ J/ (mol)} (^{\circ}\text{C})) / (0.385 \text{ J/g}^{\circ}\text{C})$$

$$M_{\text{copper}} = 64.7792 \text{ g/mol}$$

➤ Therefore the molar mass of copper is 64.78 g/mol

6. Since you know the identity of the metal, calculate a percent error with respect to the known specific heat capacity AND known molar mass of the metal.

$$\% \text{ error} = (M_{\text{experimental}} - M_{\text{theoretical}}) / (M_{\text{theoretical}}) \times 100\%$$

$$\% \text{ error} = (64.78 \text{ g/mol}) - (63.55 \text{ g/mol}) / (63.55 \text{ g/mol}) \times 100\%$$

$$\% \text{ error} = 1.94\%$$

➤ Therefore the percent error with respect to the molar mass of the metal (copper) is 1.94% .

$$\% \text{ error} = (C_{\text{experimental}} - C_{\text{theoretical}}) / (C_{\text{theoretical}}) \times 100\%$$

$$\% \text{ error} = (0.385 \text{ J/g}^{\circ}\text{C} - 0.385 \text{ J/g}^{\circ}\text{C}) / (0.385 \text{ J/g}^{\circ}\text{C}) \times 100\%$$

$$\% \text{ error} = 0\%$$

➤ Therefore there is 0% error in the specific heat capacity of copper.

7. Did the mass of the metal used make a difference? Should it have?
- The mass of the metal did not make a difference because although the values were different the calculated molar mass was the same, and when calculating the percent error in respect to the molar mass, mass of the metal is not taken into consideration.

Part 2: Enthalpy of Neutralization

8. Determine the change in the temperature of the solution, ($\Delta_{\text{soln}}T$).

Trial 1:

$$\Delta T_{\text{soln}} = T_{\text{final}} - T_{\text{initial}}$$

$$T_{\text{final}} = 29.2^{\circ}\text{C}$$

$$T_{\text{initial}} = 24.9^{\circ}\text{C}$$

$$\Delta T_{\text{soln}} = (29.2^{\circ}\text{C}) - (24.9^{\circ}\text{C}) \\ = 4.3^{\circ}\text{C}$$

- Therefore the change in temperature of the solution is 4.3°C .

Trial 2:

- Therefore the change in temperature of the solution is 4.8°C .

Trial 3:

- Therefore the change in temperature of the solution is 4.6°C .

Trial 4:

- Therefore the change in temperature of the solution is 4.5°C .

9. Calculate the volume of the final solution.

Trial 1:

$$T_1/V_1 = V_2/T_2$$

$$T_1 = 24.9^{\circ}\text{C}$$

$$T_2 = 29.2^{\circ}\text{C}$$

$$V_1 = 86.2\text{mL}$$

$$V_2 = T_2 T_1 / V_1$$

$$V_2 = (29.2^{\circ}\text{C})(24.9^{\circ}\text{C}) / (86.2\text{mL})$$

$$V_2 = 8.43\text{mL}$$

- Therefore the final volume of the solution is 8.43mL.

Trial 2:

- Therefore the final volume of the solution is 7.91mL.

Trial 3:

- Therefore the final volume of the solution is 7.63mL.

Trial 4:

- Therefore the final volume of the solution is 7.66mL.

10. Calculate the mass of the final solution, assuming the final solution to have a density of approximately 1.0 g/mL. How does this compare to your measured mass? Which is more accurate? Does it matter?

Trial 1:

$$m_{\text{final sol'n}}=?$$

$$d= 1.0 \text{ g/mL}$$

$$V_{\text{sol'n}}= 8.43\text{mL}$$

$$m=dv$$

$$m_{\text{final}}= (1.0 \text{ g/mL}) (8.43\text{mL})$$

$$m_{\text{final}}= 8.43 \text{ g}$$

- Therefore the mass of the final solution is 8.43g, this mass is not as accurate as the one determined on the analytical scale. This mass is assuming that all the reactants diluted into the solution and there was no excess.

Trial 2:

- Therefore the mass of the final solution is 7.91g.

Trial 3:

- Therefore the mass of the final solution is 7.63g.

Trial 4:

- Therefore the mass of the final solution is 7.66g.

11. Calculate the energy released, assuming that the specific heat of the final solution is the same as that of water, 4.184 J/g°C/.

Trial 1:

$$q=mc(\text{delta}T)$$

$$m= \text{mass foam cup} + \text{solution} - \text{mass of foam cup}$$

$$m=(88.7711\text{g}) - (1.87\text{g})$$

$$= 86.9011\text{g}$$

$$C= 4.184 \text{ J/g}^\circ\text{C}$$

$$\text{delta}T= 4.3^\circ\text{C}$$

$$q= (86.9011\text{g}) (4.184 \text{ J/g}^\circ\text{C}) (4.3^\circ\text{C})$$

$$q= 1563.45507 \text{ J}$$

$$q= 1.6 \times 10^3 \text{ J}$$

- Therefore the amount of energy released assuming that the specific heat is the same as water is $1.56 \times 10^3 \text{ J}$.

Trial 2:

- Therefore the amount of energy released is $1.74 \times 10^3 \text{ J}$.

Trial 3:

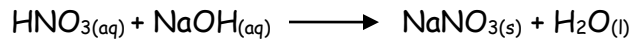
- Therefore the amount of energy released is $1.67 \times 10^3 \text{ J}$

Trial 4:

- Therefore the amount of energy released is $1.64 \times 10^3 \text{ J}$.

12. Calculate the amount (mol) of the limiting reagent ($\text{OH}_{(aq)}$).

Trial 1:



Volume of $\text{NaOH}_{\text{graduated cylinder}} = 41.0 \text{ mL} = 0.041 \text{ L}$

Concentration of $\text{NaOH} = 1.0 \text{ mol/L}$

$$n_{\text{NaOH}} = c \times v$$

$$n_{\text{NaOH}} = (1.0 \text{ mol/L}) (0.041 \text{ L})$$

$$n_{\text{NaOH}} = 0.041 \text{ mol}$$

- Therefore the moles amount for the limiting reagent NaOH is 0.041 mol.

Trial 2:

- Therefore the moles amount for the limiting reagent NaOH is 0.043 mol.

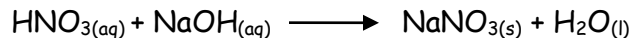
Trial 3:

- Therefore the amount of moles for the limiting reagent NaOH is 0.045 mol.

Trial 4:

- Therefore the amount of moles for the limiting reagent of NaOH is 0.043 mol.

13. Calculate the amount (mol) of water formed in the neutralization reaction.



Trial 1:

- Limiting reagent is NaOH , since there is a 1:1 mole ratio the amount moles of water produced is 0.041 mol.

Trial 2:

- The amount of mol of water produced is 0.043 mol.

Trial 3:

- The amount of moles of water produced is 0.045 mol.

Trial 4:

- The amount of moles of water produced is 0.043 mol.

14. Determine the heat of neutralization per mole of water.

Trial 1:

$$m_{\text{sol'n}} = (\text{mass of foam cup} + \text{solution}) - (\text{mass of foam cup}_{\text{empty}})$$

$$m_{\text{sol'n}} = (88.7711\text{g}) - (1.87\text{g})$$

$$m_{\text{sol'n}} = 86.9011\text{g}$$

$$C_{\text{sol'n}} = C_{\text{H}_2\text{O}} = 4.184 \text{ J/g}^\circ\text{C}$$

$$\Delta T = 4.3^\circ\text{C}$$

$$q = (m_{\text{sol'n}}) (C_{\text{sol'n}}) (\Delta T)$$

$$q = (86.901\text{g}) (4.184 \text{ J/g}^\circ\text{C}) (4.3^\circ\text{C})$$

- $q = 1.6 \times 10^3 \text{ J}$.

molar heat of neutralization = enthalpy change / moles of H₂O produced

molar heat of neutralization = $(1.6 \times 10^3 \text{ J}) / (0.041 \text{ mol})$

- molar heat of neutralization = $3.9 \times 10^4 \text{ J/mol}$.

Trial 2:

- Therefore the molar heat of neutralization is $4.1 \times 10^4 \text{ J/mol}$.

Trial 3:

- Therefore the molar heat of neutralization is $3.7 \times 10^4 \text{ J/mol}$.

Trial 4:

- Therefore the molar heat of neutralization is $3.8 \times 10^4 \text{ J/mol}$.

15. Compare the heats of neutralization per mole of water for the two strong acids.

- The heats of neutralization for the HNO₃ are greater than those of the HCl. The difference is only a couple thousand joules per mol. Both acids were of the same concentration, however they differed in their change in temperature which overall affected the molar heats of neutralization.

16. Calculate percent errors for the the experimental values of heat of neutralization with respect to literature values.

- No literature value was found.

17. How do the two trials for each acid compare? Did the volume of base used affect the result? How do the values for the enthalpies of neutralization for the two different acids compare? Did you expect the result you obtained? Why?

- The trials of the two acids reported similar values as their volumes slightly differed. As the reactions progressed both acids and the common base NaOH neutralized at around the same temperature. The amount of base used remained constant which allowed for the acid to completely dissociate. The values of enthalpy varied by only a range of 1000 J/mol approximately, since similar molar values were used and the reaction was in a 1:1 ratio. I expected to have high enthalpy values, considering the experiment was conducted in a sealed calorimeter, I had anticipated that there would be a higher retention of energy in the container.

Part 3: Enthalpy of Dissolution of a Salt

18. Determine the change in temperature of the solution, ($\Delta_{\text{sol'n}} T$)

Trial 1:

$$(\Delta_{\text{sol'n}} T) = T_{\text{final}} - T_{\text{initial}}$$

$$T_{\text{final}} = 21.0^{\circ}\text{C}$$

$$T_{\text{initial}} = 24.0^{\circ}\text{C}$$

$$\begin{aligned}(\Delta_{\text{sol'n}} T) &= (21.0^{\circ}\text{C}) - (24.0^{\circ}\text{C}) \\ &= -3.0^{\circ}\text{C}.\end{aligned}$$

- Therefore the change in temperature of the solution is -3.0°C .

Trial 2:

- Therefore the change in temperature of the solution is -3.7°C .

19. Calculate the energy released/absorbed by the solution (q), using its specific heat and mass.

Trial 1:

$$q = mc(\Delta T_{\text{sol'n}})$$

$$m = 1.51 \text{ g}$$

$$c = 3.815 \text{ J/g}^{\circ}\text{C}$$

$$\Delta T_{\text{sol'n}} = -3.0^{\circ}\text{C}$$

$$q = (1.51\text{g})(3.815\text{J/g}^{\circ}\text{C})(-3.0^{\circ}\text{C})$$

$$q = -17.3 \text{ J}$$

- Therefore the amount of energy released by the solution is 17.3 J.

Trial 2:

- Therefore the amount of energy released by the solution is 21.2 J.

20. Calculate the enthalpy of dissolution, ($\Delta_{\text{s}}H^{\circ}$), per mole of salt.

Trial 1:

$$Q = 17.3 \text{ J released}$$

$$\text{Moles of solute} = \text{mass} / \text{molar mass}$$

$$\text{Moles of solute} = (1.51\text{g}) / (74.55\text{g/mol})$$

$$\text{Moles of solute} = 0.020 \text{ mol}$$

Amount of energy released per mole of solute:

$$(\Delta H) = q/n$$

$$(\Delta H) = (-17.3 \text{ J}) / (0.020 \text{ mol})$$

$$(\Delta H) = -865 \text{ J/mol}.$$

- Therefore the enthalpy of dissolution is -865 J per mole of salt.

Trial 2:

- Therefore the enthalpy of dissolution is $-1.1 \times 10^3 \text{ J}$ per mole salt.

21. Attempt to find a literature value for the enthalpy of dissolution of the salt (but make SURE you are looking for the correct quantity!). If you find a literature value, calculate the percent error.

- No literature value was found.

22. Did the mass of the salt used affect your result? Should it have?

- The mass of the salt did not affect the calculation because only the mole value and the quantity of heat were used to calculate the percent error. It should not have affected the calculation directly.

Discussion:

After conducting Experiment 2, the data collected shows the various enthalpies, and heats of neutralization as well as molar masses from the varying reactions that took place. As shown in figures 1-8, the varying temperature was plotted against time to measure the enthalpy change of the reactions in a calorimeter. Three separate sections were performed to gather data, of a metal, neutralization reaction of HCl and HNO₃ with NaOH and of an unknown Salt. These reactions were conducted using a styrofoam cup calorimeter and with the help of Lab Quest 2.

There were various possible errors that could have occurred throughout the experiment, one issue is that the calorimeter was made of styrofoam and as a result some heat may have escaped the contraption, a higher quality material would allow for more accurate results. One other issue was that the substances from previous trials/experiments may have been emptied from the calorimeter which could lead to other reactions taking place. Labquest 2 was used to calibrate and measure the changing temperature of the reactions, however it could not be 100% accurate resulting in some error. Finally, the "thermometer" from Labquest was placed in a plastic tube like structure that was very loose and kept falling into the calorimeter in between trials. This could have led to an enlargement of the hole or pieces of styrofoam falling into the calorimeter. Allowing more heat to escape making the reaction more exothermic than it actually was.

Conclusion:

Experimentally determined was the specific and approximate molar mass of the metal, copper. The experimentally determined molar mass was 64.78 g/mol, and the specific molar mass was 63.55 g/mol. As well the enthalpy of neutralization of both strong acids HNO₃ and HCl were determined to be, 3.9×10^4 J/mol (HNO₃) and 3.7×10^4 J/mol (HCl). Finally the enthalpy of solution of an unknown salt was also determined, -865 J per mole of salt. The percent error with respect to molar mass and determined enthalpies were calculated, which relate to the aforementioned possible errors (see discussion).

Table 1: Specific Heat Capacity of a Metal

Data	Trial 1	Trial 2
Metal	Copper	Copper
Mass of metal (g)	13.397	10.008
Volume of water _{calorimeter} (mL)	20.0	20.0
Mass of foam cup _{empty} (g)	1.87	1.87
Mass of foam cup + H ₂ O	20.1805	20.1805
Temperature of boiling H ₂ O (°C)	100	100

Table 2: Enthalpy of Neutralization (HNO₃ + NaOH → ...)

Data	Trial 1	Trial 2
Volume of NaOH _{graduated cylinder} (mL)	41.0	43.0
Volume of NaOH _{beaker} (mL)	50.0	50.0
Concentration of NaOH (mol/L)	1.0	1.0
Volume of HNO ₃ _{graduated cylinder} (mL)	45.0	49.0
Volume of HNO ₃ _{beaker} (mL)	50.0	50.0
Concentration of HNO ₃ (mol/L)	1.1	1.1
Mass of foam cup + solution (g)	88.7711	45.1181

Table 3: Enthalpy of Neutralization (HCl + NaOH → ...)

Data	Trial 1	Trial 2
Volume of NaOH _{graduated cylinder} (mL)	45.0	43.0
Volume of NaOH _{beaker} (mL)	50.0	50.0
Concentration of NaOH (mol/L)	1.0	1.0
Volume of HCl _{graduated cylinder} (mL)	46.0	45.0
Volume of HCl _{beaker} (mL)	50.0	50.0
Concentration of HCl (mol/L)	1.1	1.1

Mass of foam cup + solution (g)	91.7520	87.5320
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Table 4: Enthalpy of Solution (Unknown Salt A)

Data	Trial 1	Trial 2
Solution	Salt A	Salt A
Molar mass of salt (g/mol)	74.55	74.55
Mass of salt (g)	1.51	1.50
Specific heat capacity (J/g°C)	3.815	3.815
Volume of H ₂ O (mL)	20.0	20.0
Mass of foam cup + H ₂ O (g)	20.8690	21.1511
Mass of foam cup + solution (g)	21.0251	21.8644

Figure 1

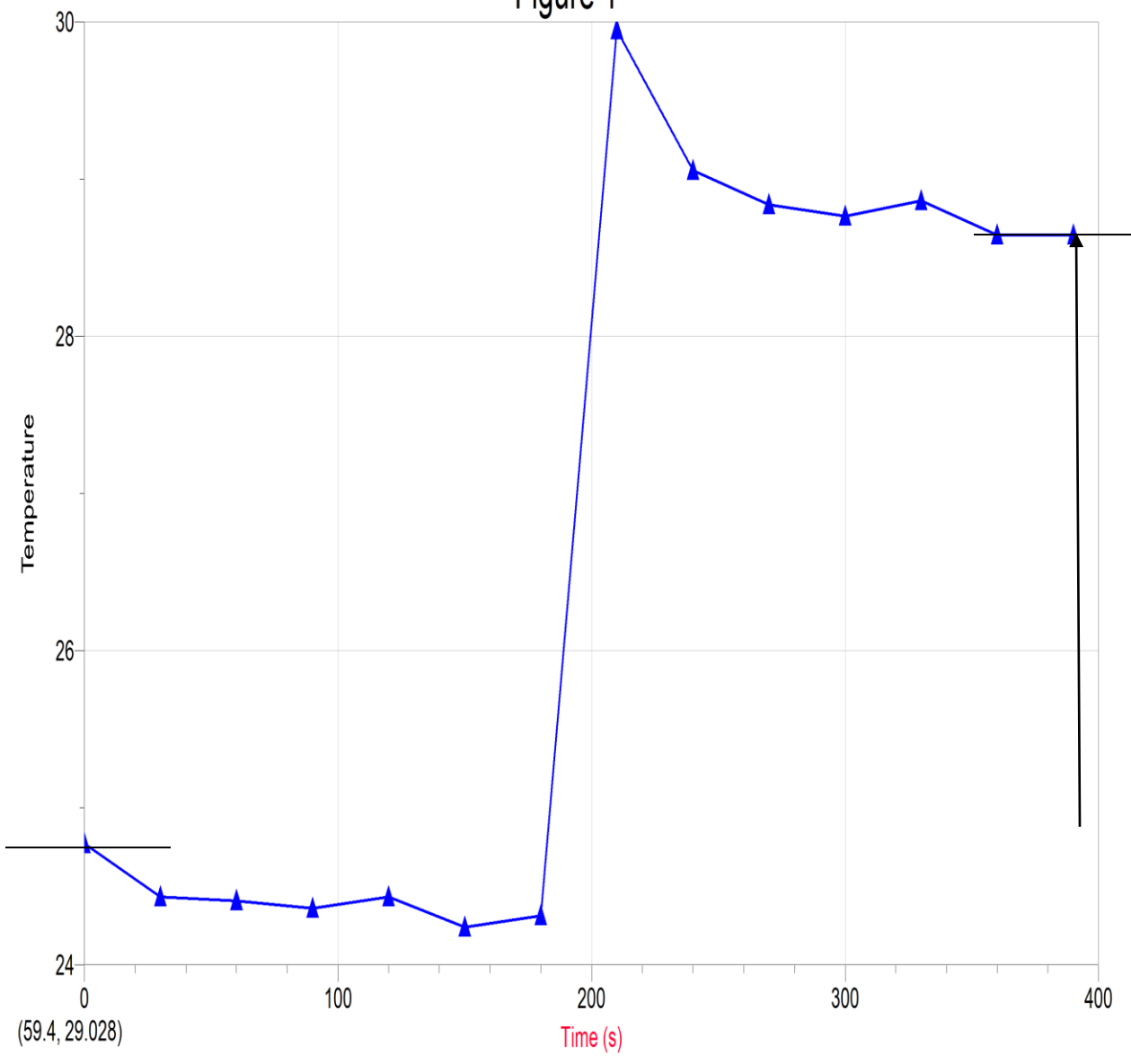


Figure 2

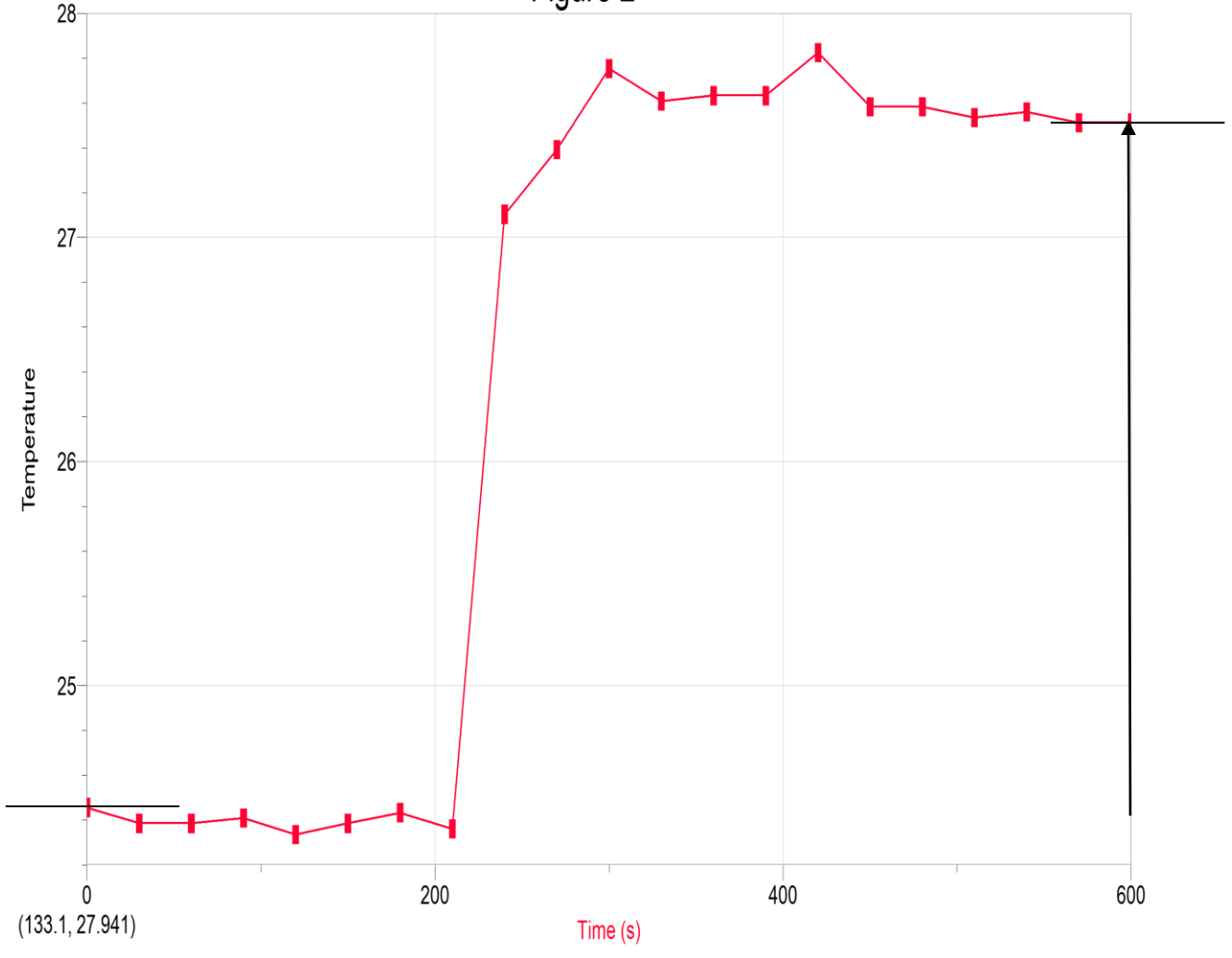


Figure 3

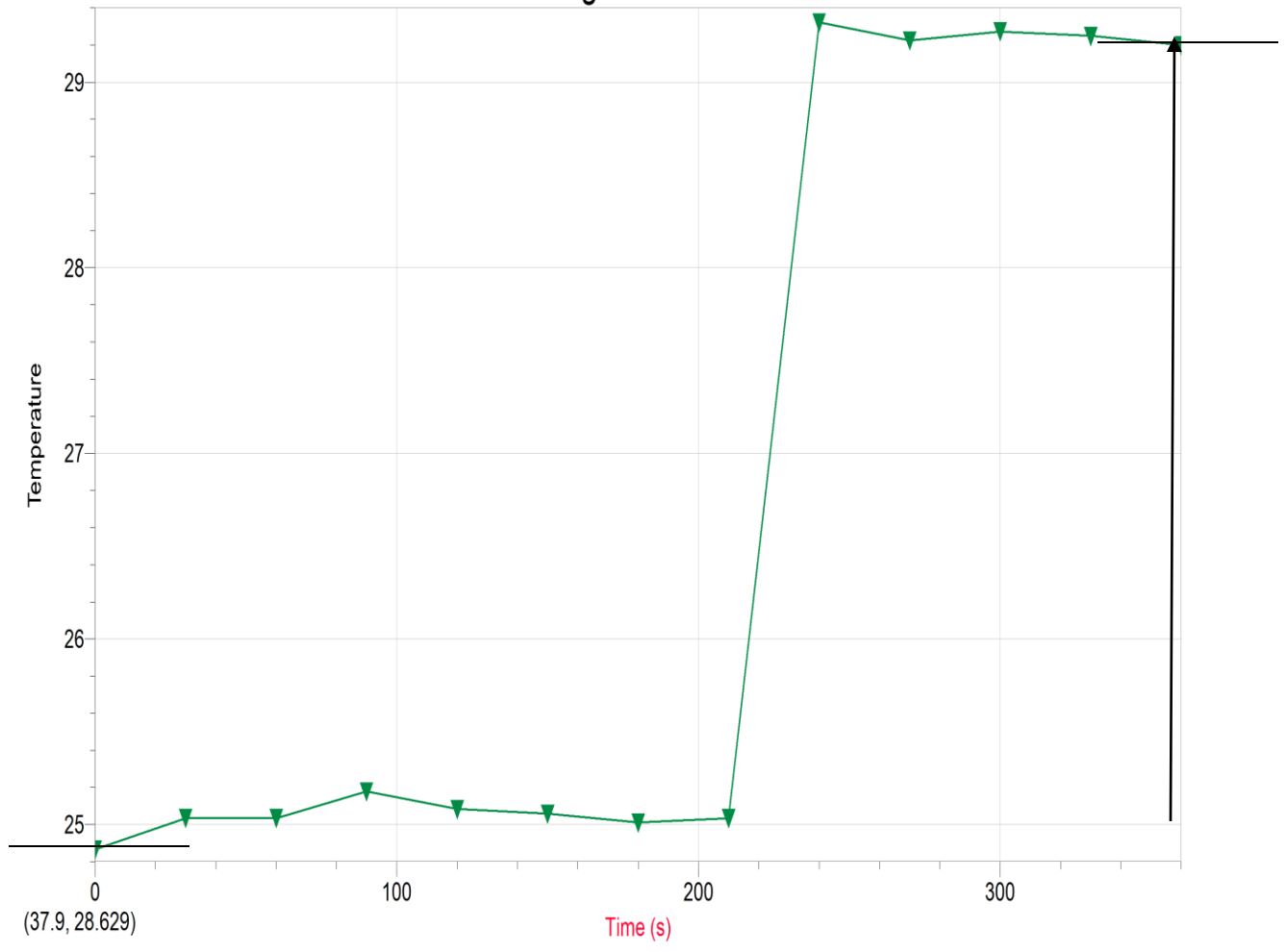


Figure 4

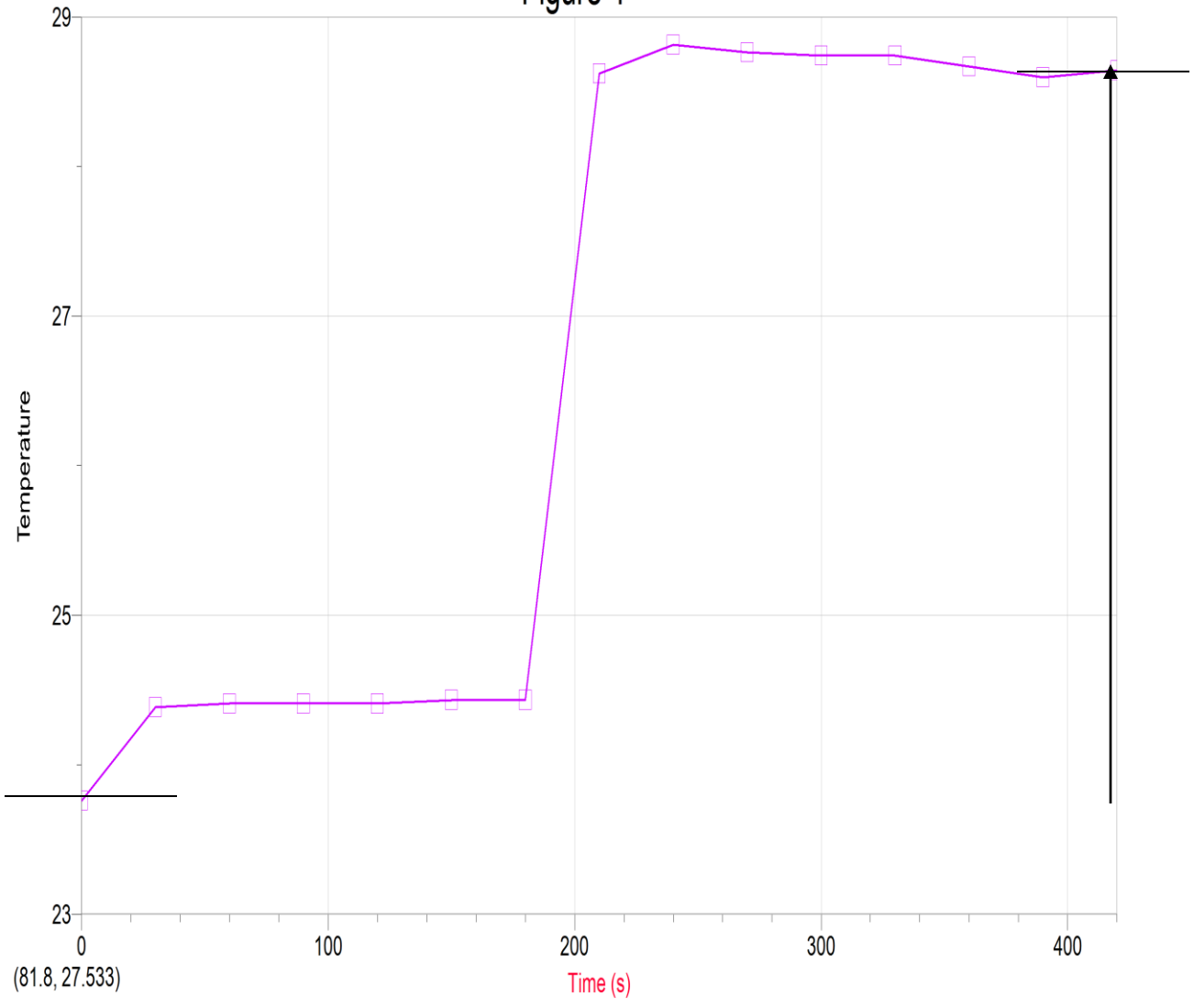


Figure 5

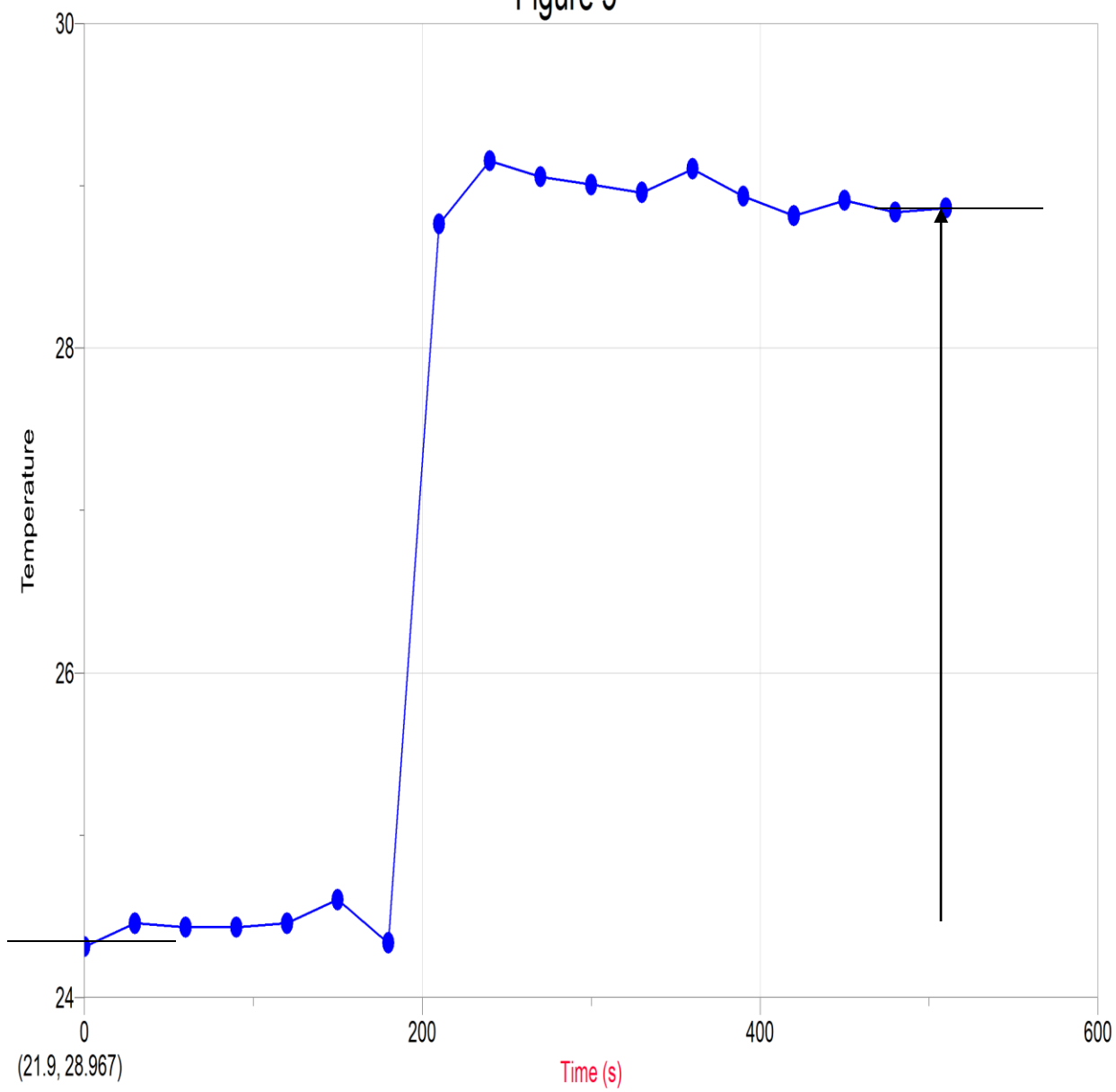


Figure 6

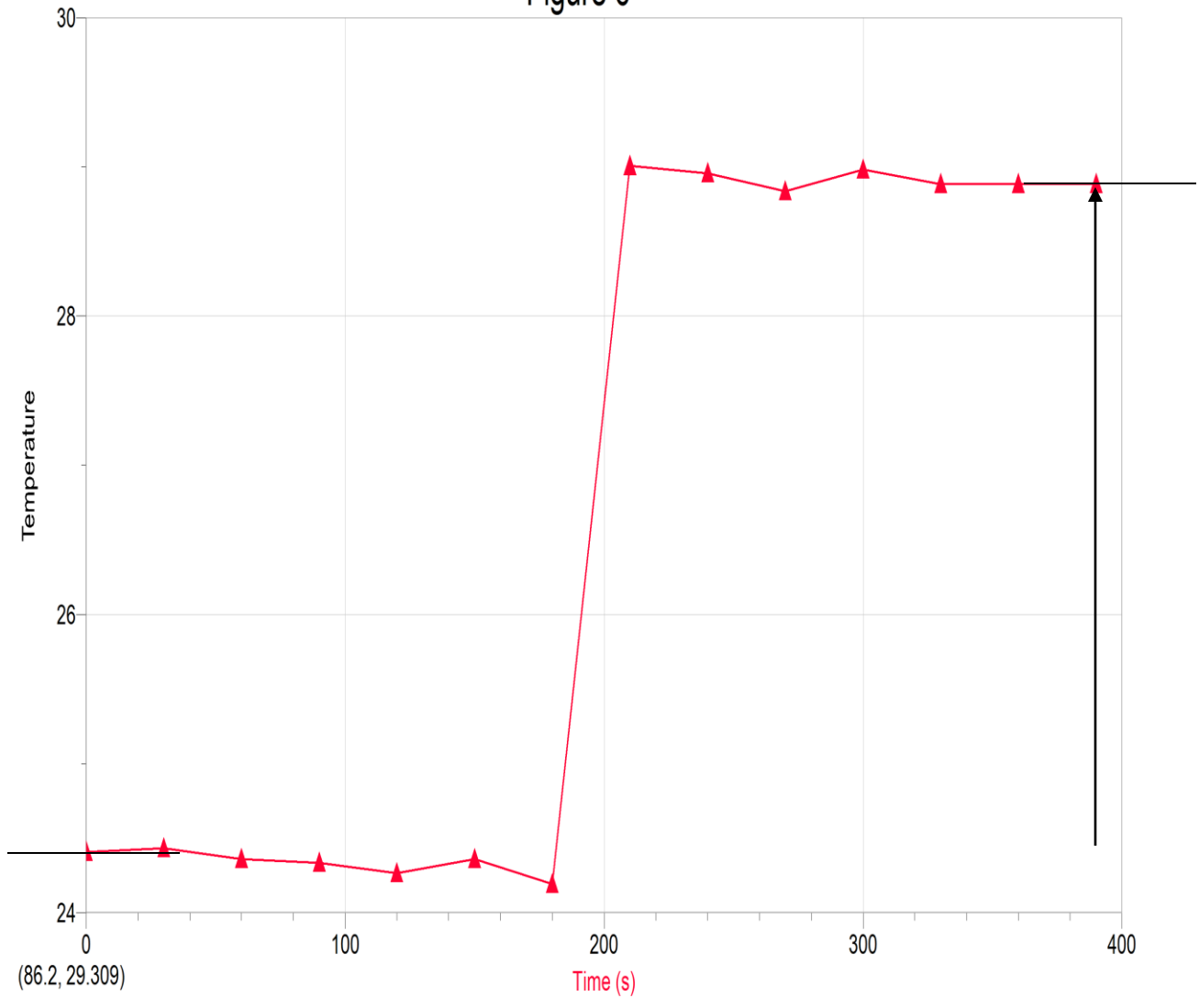


Figure 7

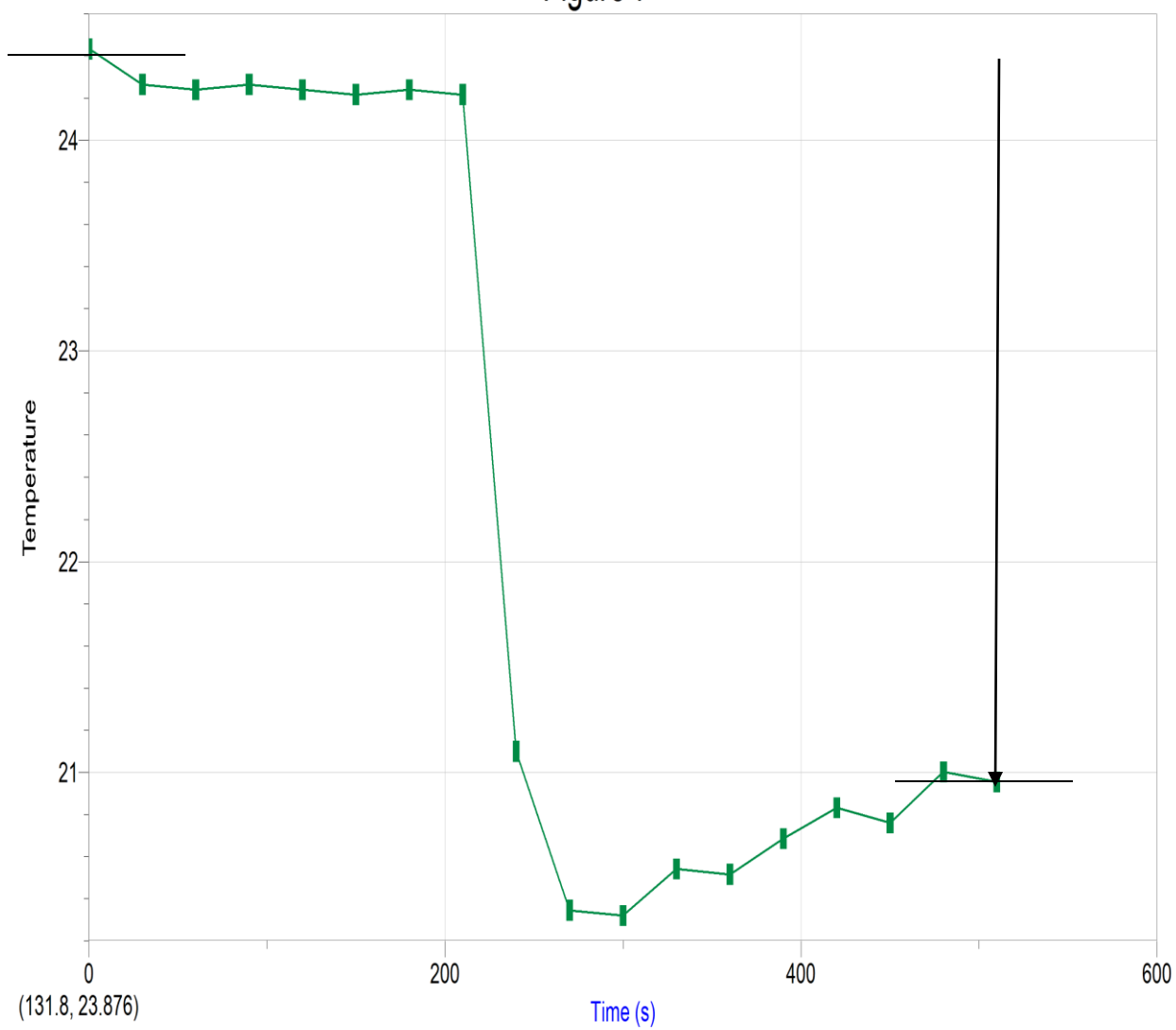


Figure 8

