Lebanese University
Faculty of Science II

Scientific Report

Thermodynamics lab P3303

Experiment III: Calorimetry

By

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I. Abstract

This experiment aims to determine the latent heat of vaporization of water using a calorimeter. Steam at is condensed into a known mass of cooler water inside the calorimeter. The resulting temperature increase is measured, allowing the calculation of the heat transferred from the steam to $100\,^{\circ}\mathrm{C}$ the water and calorimeter. Using the conservation of energy principle, the latent heat of vaporization is obtained. The average experimental value was found to be approximately 416.3 cal/g, which is decently large in comparison to the theoretical value of 540 cal/g and the appropriate uncertainties and statistics were calculated in order justify this deviation in the experimental value of the latent heat.

key words: *latent heat, calorimeter, temperature, mass*

II. Introduction

The calorimeter is an instrument used to determine the specific heat capacity of solid and liquid substances. This is achieved by measuring temperature changes and the corresponding heat exchange between the substance and a known mass of water. It can also be employed to determine the latent heat of a material during a phase change. In particular, the latent heat of vaporization represents the amount of energy absorbed when water changes from liquid to vapor (or released when vapor condenses back to liquid). In this experiment, a calorimeter is used to create an isolated system, ensuring that the heat exchanged between the vapor, water, and the calorimeter occurs without any loss or gain from the surroundings. The principle of conservation of energy governing the process is expressed as:

$$(m_0 + m)c(t_2 - t_1) = m_v L_v + m_v c(100 - t_2) \tag{1}$$

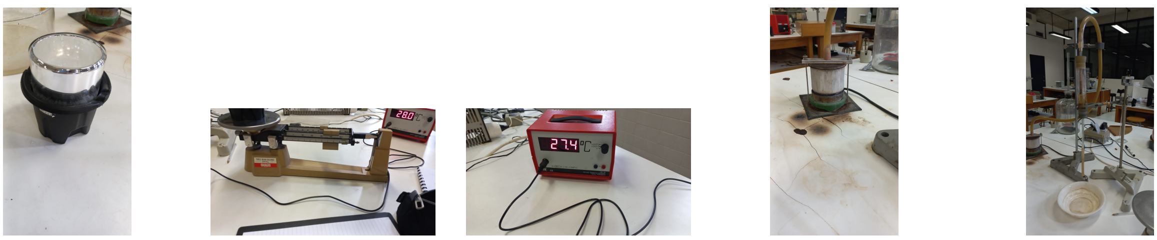
Where m_0 is the water's equivalent of the calorimeter(g), m is the mass of the water (g), m_v is the mass of vapor(g), t_1 is the initial temperature of water (°C), t_2 is the final temperature (°C), c is the specific heat of water ($1\ \mathrm{cal/g°C}$), and L_v is the latent heat of vaporization of water(cal/g)

Rearranging Equation (1) gives the expression for the **latent heat of vaporization**:

$$L_v = \frac{(m_0 + m)c(t_2 - t_1)}{m_v} - c(100 - t_2) \tag{2}$$

III.Procedure

In this experiment , the procedure is as follows: Start by weighing the empty *calorimeter* with a *triple beam balance*. Then, the calorimeter was half-filled with water and the combined mass of the calorimeter and water was recorded. The mass of the water (m) was obtained by subtracting the mass of the empty calorimeter from this value. Also, the initial temperature of the water (t_1) was measured using a *thermometer* and a *vapor generator* was connected to the calorimeter through a dry delivery tube, ensuring that only dry steam-entered and that no liquid water was carried into the calorimeter. Once a steady flow of steam was established, the outlet of the tube was carefully inserted into the water inside the calorimeter, allowing the vapor to condense for a short and controlled period. Furthermore, the steam inlet was removed and the final equilibrium temperature of the water (t_2) was recorded. Finally, the calorimeter with the water and vapor was measured to find the mass of the condensed vapor (m_v). The experiment was**repeated** 4 other times *to minimize errors*.



Calorimeter | Triple Beam Balance | Thermometer | Vapor generator | Delivery tube

Figure 1: Five experimental photos arranged in a single row.

Table 1: Instruments and Their Descriptions

Instrument Name	Description
Calorimeter	Used to measure heat change during a reaction.
Triple Beam Balance	Measures mass by balancing an unknown mass against sliding weights on three beams.
Thermometer	Measures the temperature.
Vapor Generator	Produces vapor by heating a liquid.
Dry Tube	Carries vapor created by the vapor generator.

IV. Results and Analysis

This section will include results of the experiment, an error analysis of those results, and the discussion of these errors with some suggestions. The detailed calculations will be placed in section VI.

IV.1 Experimental calculations

The measurements of the different masses and and temperatures using the triple beam balance and thermometer respectively, for each round of the experiment, are presented in **Table 2**.

Table 2: Measured values of masses and temperature

Experiment Round	1	2	3	4	5
Initial Temperature (°C)	27.3	27.6	27.9	28.0	27.9
Mass of Calorimeter and Water (g)	464.8	522.0	496.1	526.2	516.6
Final Temperature (°C)	41.5	35.8	38.6	35.1	41.7
Mass of Calorimeter, Water, and Vapor (g)	469.8	525.0	499.4	530.0	525.5

The mass of the **calorimeter** is $331.6g$.

IV.2 Error Analysis

The theoretical value of the latent heat of vaporization of water is approximately $540cal/g$ which gives a **percentage error** of:

$$\% \text{ Error} = 22.9\%$$

Table 3 presents the values of the masses of water and vapor that were deduced from Table 2's values of the masses and the values of L_v that were found by **Equation 2**. **Table 4** computes the uncertainties on the masses of water and vapor (Δm_i), the uncertainty on each of the temperatures (Δt_i), the mean values of all the temperatures and masses of water and vapor, the standard deviation, standard error (SE) and the *total* propagation error $\Delta \bar{L}_{vt}$.

Table 3: Extra calculated values and the final result of L_v

Experiment Round	1	2	3	4	5
Mass of Water (g)	133.2	190.4	164.5	194.6	185
Mass of Vapor (g)	5	3	3.3	3.7	8.9
L_v **(cal/g)**	390.8	524.6	542.3	356.5	267.3

From the table on the right and **Equation 2** the mean value of the latent heat is $\bar{L}_v = 416.3$ cal/g.

Table 4: All statistical errors and uncertainties

$\Delta m_i(g)$	$\Delta t_i(°C)$	$\bar{t}_1(°C)$	$\bar{t}_2(°C)$	$\bar{m}(g)$	$\bar{m}_v(g)$	σ(cal/g)	SE(cal/g)	$\Delta\bar{L}_{vt}$(cal/g)
±0.071	±0.1	±27.4	±38.5	±173.5	±4.8	±104	±46.5	±97.6

All the values with a *bar* on top are mean values, σ is the standard deviation of $\bar{L}_v$, and SE is the standard error. All of the values are to be used to calculate the total propagation error $\Delta\bar{L}_{vt}$.

IV.3 Discussion of Errors

The experimental determination of the latent heat of vaporization of water yielded an average value of $416.3cal/g$, which is relatively large, corresponding to a of 22.9% difference from the theoretical value. The source of this difference includes: random errors that are related to environmental factors like ambient temperature and atmospheric pressure, human errors while recording data, reading errors of temperature and the masses which helps find the range of the values due to the instrument's small inaccuracy, the standard error of the mean value of L_v with its corresponding standard deviation which shows how deviated the mean value found is from the actual value. All in all, the *final* result of the latent heat of vaporization is:

$$\bar{L}_v \pm \Delta L_{vt} = 416.3 \pm 46.9(cal/g)$$

The theoretical value of 540 cal/g does not unfortunately belong to the range of uncertainty. This is because of the inaccuracy of the measurements and because a lot of the water was lost as vapor instead of being condensed during the experiment.

To minimize the errors, one must make sure to precisely and accurately measure the mass and temperature, agitate the calorimeter well during the experiment in order not to lose excess mass of water as vapor, and remember to never misrecord/forget to record any data given as well as repeat the experiment as many times as possible.

V. Conclusion

In conclusion, it has been found that the difference between the experimental and theoretical value of the latent heat of vaporization was 22.9% which exceeds the reasonable range. This difference is due to the various instrumental and reading errors of the thermometer and the triple beam balance, blunders while recording data and most importantly, the **incomplete condensation** of the vapor in the calorimeter which lead to water being lost as vapor. The appropriate errors were the computed in order to mathematically show the difference between the 2 values of the latent heat of vaporization.

VI. Appendix

VI.1 Constants

Water's equivalent:

$$m_0 = 25g$$

Theoretical Latent Heat of Vaporization of Water:

$$L_v = 540 \text{ cal/g}$$

Specific Heat of Water:

$$c = 1 \text{ cal/g } ^\circ C$$

VI.2 Additional Formulas

Mass calculations:

$$m_v = m_{w+c+v} - m_{w+c} \tag{3}$$

$$m_w = m_{w+c} - m_c \tag{4}$$

Where m_v is the mass of water vapor, m_{w+c} is the mass of the water and calorimeter, and m_{w+c+v} is the mass of water, calorimeter and vapor.

VI.3 Statistical and Uncertainty Calculations

Mean of all experimental values of L_v:

$$\bar{L}_v = \frac{1}{n}\sum_{i=1}^{n} L_{vi} = \frac{390.8 + 524.6 + 553 + 356.5 + 267.3}{5} = 416.3 \text{ cal/g} \tag{5}$$

Percentage Error calculation:

$$\% \text{ Error} = \left|\frac{L_{\text{vexp}} - L_{\text{vtheo}}}{L_{\text{vtheo}}}\right| \times 100 = \left|\frac{416.3 - 540}{540}\right| \times 100 = 22.9\% \tag{6}$$

Uncertainties on the masses:

$$\Delta m_c = \Delta m = \Delta m_{w+c+v} = 0.5 \times \mathit{smallest\ div} = 0.05 \text{ g} \tag{7}$$

$$\Delta m_w = \Delta m_v = \sqrt{0.05^2 + 0.05^2} = 0.071 \text{ g} \tag{8}$$

Uncertainty on the ALL temperatures:

$$\Delta t_i = \mathit{smallest\ value} = 0.1^\circ C \tag{9}$$

Additional mean values:

$$\bar{t}_1 = 27.4^\circ C$$

$$\bar{t}_2 = 38.5°C$$

$$\bar{m}_w = 173.5 \text{ g}$$

$$\bar{m}_v = 4.78 \text{ g}$$

Refer to **Equation 5**

Standard Deviation:

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(L_{vi} - \bar{L}_v)^2} = 104 \text{ cal/g} \tag{10}$$

$$\text{SE} = \frac{\sigma}{\sqrt{n}} = 46.5 \text{ cal/g} \tag{11}$$

Propagation Error:

$$(\Delta \bar{L}_v)^2 = \left(\frac{\partial \bar{L}_v}{\partial m}\Delta m\right)^2 + \left(\frac{\partial \bar{L}_v}{\partial m_v}\Delta m_v\right)^2 + \left(\frac{\partial \bar{L}_v}{\partial \bar{t}_1}\Delta \bar{t}_1\right)^2 + \left(\frac{\partial \bar{L}_v}{\partial \bar{t}_2}\Delta \bar{t}_2\right)^2 = 34.8 \text{ cal/g} \tag{12}$$

Total Error:

$$\Delta L_{vt} = \sqrt{(\Delta \bar{L}_v)^2 + (SE)^2} = 46.9 \text{ cal/g} \tag{13}$$

VII. References

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