How to Write a Lab Report

Report Sections			Explanation
A.1	Title Page		
A.2	Abstract		
A.3	Table of Contents		
A.4	Introduction	• Background / Theory • Purpose • Governing Equations • Discovery Question (**DQ**)	In this section, you describe **what** you are trying to find and **why**. Background and motivation are used to provide the reader with a reason to read the report.
A.5	Methods	• Experiment Overview • Apparatus • Equipment Table • Procedures	In this section, you explain **how** question addressed is answered. Clearly explain your work so it could be repeated.
A.6	Results	• Narrate (like a story) • Tables and Graphs • Equations in Variable Form • Uncertainties • Units! • Indicate Final Results	In this section, you present the **results** of your experiment. Tables, graphs, and equations are used to summarize the results. Link equations and visuals together with narrative, like a story. Remember your audience.
A.7	Discussion	• Answer **DQ** • Theoretical Comparison • Explanation of Anomalies / Error • Conclusion / Summary • Future Work	In this section, you **explain** and **interpret** your results. Insert your opinion, backed by results. Discuss issues you had and how this could be corrected in the future. The conclusion is a summary of your results and discussion.
A.8	References		
A.9	Appendices – Raw Data, Sample Calcs, Lab Notebook, etc.		

Color Coding

Required Parts

Writing Suggestions

A Show Me!

The following sections show example lab report sections which have been annotated. In each section, BLUE indicates the required components of each section and YELLOW are suggestions to successfully write those parts.

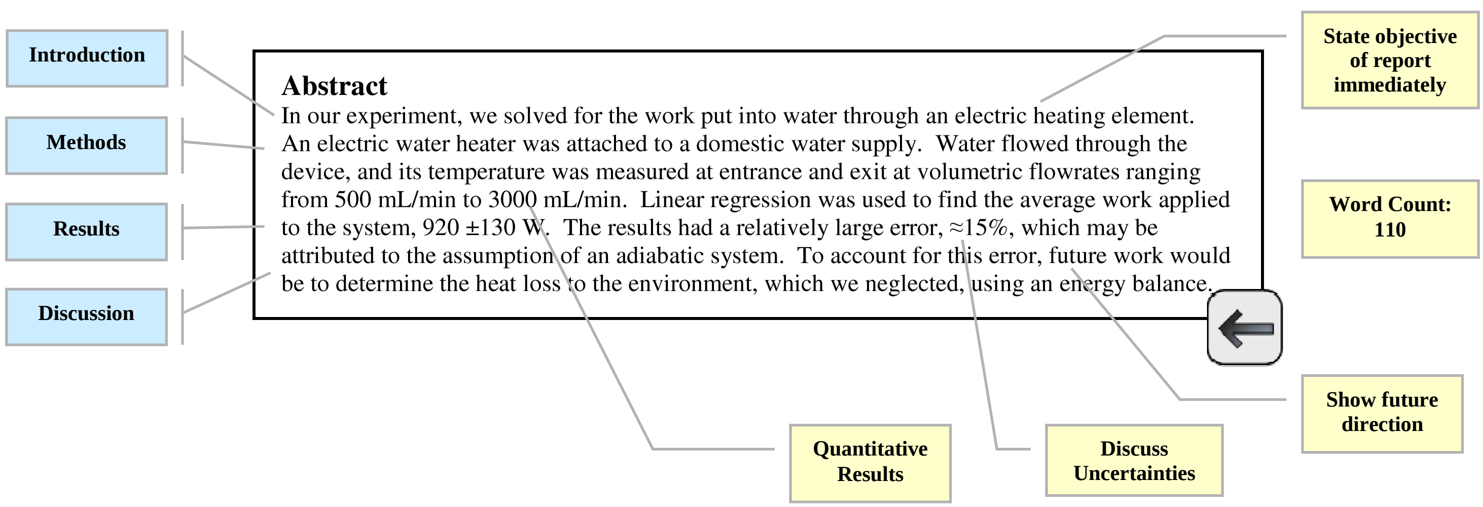
A.1 Title Page

The title page contains a descriptive title of the document, the author's name, affiliation, and date. List any people who performed the work with you. This title page must conform to established standards of your class. Ask your instructor for his or her preference.

A.2 Abstract

The abstract's purpose is to summarize the information contained in the report for someone who doesn't have the time or resources to read it. It's inclusion as a report "section" is slightly misleading. In many ways, the abstract is a document all on its own; it includes all the same parts of your report and its major findings.

Quantitative results and their uncertainties should be included when possible. It must contain parts from each major section of your report. Many times this is the only thing anyone will read about your report. It should be no more than 400 words. This is not a "teaser."



Abstract

In our experiment, we solved for the work put into water through an electric heating element. An electric water heater was attached to a domestic water supply. Water flowed through the device, and its temperature was measured at entrance and exit at volumetric flowrates ranging from 500 mL/min to 3000 mL/min. Linear regression was used to find the average work applied to the system, 920 ±130 W. The results had a relatively large error, ≈15%, which may be attributed to the assumption of an adiabatic system. To account for this error, future work would be to determine the heat loss to the environment, which we neglected, using an energy balance.

You might be tempted to write this first, as it is appears first chronologically in the report; however, because the abstract is a summary of the entire report, you should write it last. This is when you will be most familiar with the report and its major findings.

A.3 Table of Contents

The table of contents' purpose is to allow the reader to easily find information. It also informs the reader about the report's organization. List page numbers with descriptive titles for the sections. This should be its own page. See this guide's TOC for an example.

A.4 Introduction

This explains **what** and **why** you are doing the experiment. It should show necessity for the experiment through theory and past work.

Hume 1

Introduction

A fundamental concept in mechanical engineering is the first law of thermodynamics, which states that internal energy is conserved in a control volume. This law has many applications in engineering, such as: heat exchangers, pumps, turbines, HVAC mixing and refrigeration cycles. It is used to understand the states of fluids as they enter or leave a control volume. The general form of the first law is Equation 1.

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum_{in} \dot{m}_{in}\left(h_{in} + \frac{V_{in}^{2}}{2} + gz_{in}\right) - \sum_{out} \dot{m}_{out}\left(h_{out} + \frac{V_{out}^{2}}{2} + gz_{out}\right)$$

Equation 1: First Law

This energy balance states that heat transfer into a system ($\dot{Q}$) less the work out of a system ($\dot{W}$) plus the mass flow out ($\dot{m}_e$) times its internal energy less the mass flow in ($\dot{m}_i$) times its internal energy is equal to the energy storage term ($\frac{dE}{dt}$).

In this experiment, the first law of thermodynamics will be used with an electric water heater to answer the research question, "What size electric element is used in a given water electric heater?" We hypothesize it will be close to 1 kW, which is the approximate average of most other water heaters of similar size and shape.

Name / Page #

Background / Theory

Provide motivation for people to read on

Governing Equations

Equations are set apart in text for emphasis

Equations are numbered and explained

Purpose

Discovery Question (DQ)

Explicitly stating the report question in the text of the introduction will help you keep the report in focus. As you continue writing, keep this question in mind—this is why you are making this report.

At this point, also notice that you haven't said anything about your experiment.

A.5 Methods

This section explains **how** the report question above was answered. After reading this section, the reader should be able to completely reproduce the experiment to verify the results.

Hume 2

Method

Tap water was passed through the electric water heater at flow rates ranging from 50 ml/min to 300 ml/min. The input and output temperatures were recorded. The information was then used with the first law to approximate the work by the heating element performed on the system.

Experiment Overview

A high level description of the experiment instantly informs the audience

"Describe the forest before you describe the Trees."

Apparatus

The experimental apparatus includes a plastic container, the heater, measuring 6” x 6” x 12”. One half inch ports were located at the upstream and downstream sides of the heater and labeled ‘in’ and ‘out’. An electric power cord is attached to the top side of the heater and supplies 120Vac to the heater inside. The input to the heater was connected to a domestic water supply, which provided 46.1 ± 0.4 ºF water once at steady state. The output from the water heater was run through a Dwyer flowmeter, which measured and controlled flowrate, and then exited into a sink. Temperature readings were made at the inlet and exit ports of the heater with T thermocouples and an Omega temperature indicator. The experimental setup is shown in Figure 1.

Apparatus Description

“Walk Through” the apparatus description

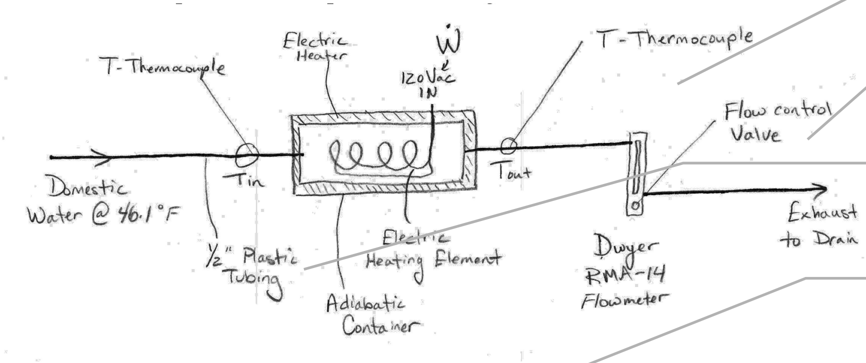


Figure 1: Apparatus

Apparatus Sketch

Enable reader to visualize the experiment

Use Descriptive Annotations

Figure Numbers & Captions

A detailed list of the equipment used in this experiment and their uncertainties are shown in Table 1.

Every equation, table, or figure is discussed in the text

Table 1: Equipment

Equipment	Uncertainty
Electric Heater	n/a
Dwyer RMA-14 Rotameter	+/- 50 ml/min
Omega T Thermocouples	+/- 1.8 ºF
Omega Temp Readout	n/a

Equipment Table

Manufacturer, model number, serial number, uncertainties,

Procedure

The tap water entering the system was varied between 500 ml/min and 3000 ml/min, in 500 ml/min increments. At each flowrate, the inlet and outlet temperatures were measured ten times when the system appeared to reach steady state.

Procedure

NO Bulleted Statements

Step-by-Step cookbook instructions

Notice the figure narration scheme so far. The report is a story of visuals linked together with text.

A.6 Results

This section of the report show what you found. Your data is manipulated to be presented nicely and explained.

Hume 3

Results

The water heated up as it passed through the heat exchanger and the temperature change appeared to correlate inversely with the flow rate. The exit temperatures of the water appear in Table 2. Inlet water temperature reached steady state at 46.1 ± 0.4 ºF.

Results Narration

Immediately begin stating results. Get right to the point.

Table 2

Flowrate [ml/min]	T_{out} [ºF]	$T_{out} – T_{in}$ [ºF]	ΔT_{out} [ºF]	$\Delta T_{out, Tot}$ [ºF]
500	87.2	41.1	± 0.1	± 1.8
1000	75.4	29.3	± 0.2	± 1.8
1500	67.0	20.9	± 0.4	± 1.8
2000	63.1	17.0	± 0.3	± 1.8
2500	59.3	13.2	± 1.2	± 2.2
3000	56.1	8.7	± 2.2	± 2.8

The uncertainty, ΔT_{out}, is the random precision error, using n=10 samples, 9 d.f., and $t_{0.025, 9}$= 2.262 from the t distribution. Equation 2 statistically approximates the true mean, μ, with the samples collected.

$$\mu = \bar{x} \pm t_{0.025,9} \frac{S_x}{\sqrt{n}} \qquad \text{(95\% C.L.)}$$

Equation 2

In the above equation, S_x is the standard deviation of the samples collected and $\bar{x}$ is the mean value of the samples. The total uncertainty in outlet temperature, $\Delta T_{out, Tot}$, was calculated by combining both the random uncertainty of the temperature readings and the bias uncertainty of the thermocouples given by the manufacturer of +/- 1.8 ºF using root sum of squares (RSS). This process is shown in Equation 3.

$$\Delta T_{out,Tot} = \sqrt{\Delta T_{out,random}^2 + \Delta T_{out,bias}^2}$$

Equation 3

The results and uncertainties were then graphed to visualize the data. Error bars were created using for temperature using data from Table 2 and errors for volumetric flowrate were from the manufacturer, shown in Table 1 This data is shown in Figure 2.

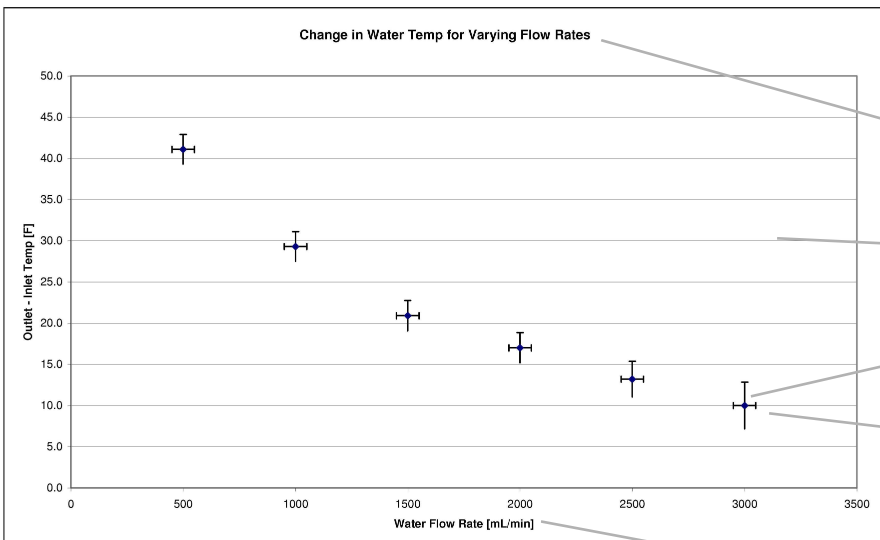


Figure 2: Experimental Results

The trend in the data seems logical as the faster the flowrate, the smaller the temperature difference between inlet and outlet will be. Uncertainty in temperature measurement grew as the flowrate increased, perhaps due to turbulent flow at the heater exit or a temperature profile in the water resulting from incomplete mixture.

Tables & Visuals

Tables have headings for each column

Units

Uncertainty

Balance tables in white space. They should look neat.

Equations in Variable

Confidence Levels shown for uncertainty work

Equations are discussed after they are presented

Supporting equations and values can be placed in prose

Narrate (Like a story)

Figures

Figure has descriptive title showing findings

Plot background is not distracting

Error Bars (Uncertainty)

Error bars were created from individual data point uncertainties

Axes are labeled with units

Every figure is discussed

So far, you have only presented your data. You haven't described what it means. That comes in the next section.

A.7 Discussion

In this section, the results are **interpreted**. Describe the why you think the data turned out like it did. Insert your scientific opinion in this section.

Hume 5

Discussion

The experimental results obtained above were used to calculate the work done on the system by the electric heater. To calculate this, the energy balance equation, Equation 1, is used.

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum_{in} \dot{m}_{in}\left(h_{in} + \frac{V_{in}^2}{2} + gz_{in}\right) - \sum_{out} \dot{m}_{out}\left(h_{out} + \frac{V_{out}^2}{2} + gz_{out}\right)$$

Equation 4

When we assume that the system is at steady state, there is no heat loss, and that velocity and potential changes are negligible, the equation reduces to Equation 5.

$$\dot{W} = \dot{m}(h_{in} - h_{out})$$

Equation 5

The equation can be further simplified by making the assumption that there will be relatively small changes in pressure and temperature over the system, so enthalpy can approximated using Equation 6.

$$h_{in} - h_{out} = c_{p,avg} \cdot (T_{in} - T_{out})$$

Equation 6

In this case, an average temperature of 60ºF will be used to get the average specific heat of water, $c_{p,avg} = 0.999 \frac{Btu}{lbm \cdot °F}$. By substituting massflow for density (ρ) times volumetric flowrate ($\dot{V}$) we get our principal analytical equation, Equation 7.

$$\dot{W} = \rho \cdot \dot{V} \cdot c_{p,avg} \cdot (T_{in} - T_{out})$$

Equation 7

For this experiment, the density of water is assumed to be 62.4 lbm/ft^3 with no uncertainty. The input water temp, T_{in}, was found to be 46.1 ± 0.4 ºF. To solve for the work put into the system, we perform a linear regression of temperature increase versus the inverse of volumetric flowrate. When this is performed, the slope (m) is an average of all data points and can directly calculate the work.

$$m = \frac{\dot{W}}{\rho \cdot c_{p,avg}}$$

Equation 8

Equation 8 can be manipulated to solve for the work. The regression analysis and confidence intervals are shown in Figure 3 .

Narrate

Reference & introduce visuals in text

Use Equation Editor

Headings and Subheadings organize the text

Explain with Equations

List your assumptions as you make them

Show the steps you performed in order. Do not skip important steps

Narrate (like a story)

Show constant values, like density, that you use in your calculations

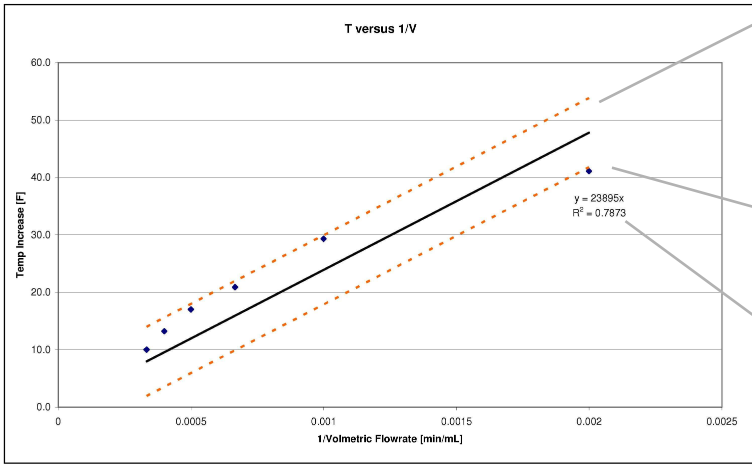


Figure 3

Confidence Intervals (Uncertainty)

Lines always indicate a regression was performed. Do not show if you didn't do one.

Confidence intervals always accompany a line of best fit

Show equation and R^2 values for regression lines

The confidence intervals were plotted using Equation 2, replacing the standard deviation of the sample with the standard error of the regression analysis. Uncertainty in the slope of the regression line was calculated with the same equation, but using the standard error of the slope from the regression analysis. Figure 3 shows a loosely fitting line, with R^2=0.787 indicating the presence of other factors we have not considered.

Discuss the quality of your results

The last data point, at 1/V of 0.002 min/mL deviated considerably from the linear model and might be considered an outlier upon further analysis.

Explanation of Anomalies

The resulting slope and uncertainty of the regression line is $m = 23900 \pm 2500 \frac{\Delta T \cdot mL}{\min}$.

Show Units!

While the work can be solved for by simply substituting the slope into Equation 8, the uncertainty in the work needs to be propagated.

$$\Delta \dot{W} = \dot{W} \cdot \sqrt{\left(\frac{\Delta m}{m}\right)^2 + \left(\frac{\Delta \rho}{\rho}\right)^2 + \left(\frac{\Delta c_{p,avg}}{c_{p,avg}}\right)^2}$$

Equation 9

All the variables here have been previously defined

It is assumed that the density of the fluid and specific heat are without error, so Equation 9 reduces to an equality of the percent errors of both the slope and work. To account for the bias errors from measurements, those errors are propagated in Equation 10, which is the propagation of Equation 7, combined with Equation 9 using RSS.

$$\Delta \dot{W} = \dot{W} \cdot \sqrt{\left(\frac{\Delta m}{m}\right)^2 + \left(\frac{\Delta \dot{V}}{\dot{V}}\right)^2 + \left(\frac{\Delta T}{T}\right)^2}$$

Equation 10

The uncertainty in volumetric flowrate and temperature measurements are found in the equipment table. After substituting values, we solved for the total work done on the system.

$$\dot{W} = \mathbf{920 \pm 130\ W}$$

Indicate Final Answer

This value seems reasonable and near our predicted value.

Does your answer make sense?

The report is now fully described.

A.7½ Conclusion / Summary

This section is a summary of the results and discussion from the report. It is still discussion, where you insert your opinion of the results. Report the key findings of the report here. It is much like the results and discussion sections of the abstract. Directly answer the report question here. Do not be vague.

> **Conclusion**
>
> The first law of thermodynamics was used to calculate the work put into the system through the electric element, which was 920 ± 130 W. The model used in this experiment was simplistic and could account for the large uncertainty in this measurement. Figure 3 showed a large uncertainty in data when performing a linear fit, with a low R^2 value and some questionable data points. A shortcoming of this model might be the assumption of an adiabatic system. The heater was constructed only of plastic and became warm during experimentation. This would indicate heat being lost to the environment, which was excluded. Inclusion of such a term would increase the work being performed by the electric heater into the system.
>
> Further experimentation could be done to measure the heat loss by the system. An ammeter could be connected to the electric heating element to measure the work going in, and a similar method, like used here, could solve for the heat loss to the surroundings.

Conclusion or Summary

Give concise, meaningful statements in Conclusion

Answer DQ

Show Key Results

List errors you discovered during experimentation

Future Ideas

A.8 References

The reference section shows where you got information that was not your own.

> Hume 9
>
> **References**
>
> Department of Mechanical Engineering (2009). *ME4031 course packet C#5025, Spring 2009.* Minneapolis: Printing Services.
>
> Kaminski, D. & Jensen, M. (2005). *Introduction to thermal and fluids engineering.* Hoboken: John Wiley & Sons.
>
> Kuehn, T., Ramsey, J., & Threlkfeld, J. (1998). *Thermal environmental engineering: third edition.* Upper Saddle River: Prentice Hall.

References

APA Citation shown here

There are many citation styles you can use such as: ASME, CMS, APA, etc. Consult a citation manual for assistance. "A Pocket Style Manual" by Diana Hacker is a good start.

Try RefWorks at the U of M library website. It will manage all your citations automatically.

A.9 Appendices

The appendix should contain information that is required, but would be distracting from the normal flow of the report. This might be raw data, lab notebook pages, regression summaries, or sample calculations.

"Don't *expect* the reader to read the appendices."
- Dr. Terry Simon, Mechanical Engineering Faculty

B Process Tips

- Be Concise.
- It is more important you are clear and direct than to follow formatting rules.
- The report organization doesn't follow the way you need to think about it to write it. To help, write a report in the following order: Methods, Results, Discussion, Intro, and Abstract.
- Use visuals. Engineering is more than prose writing.
- Be concise. Extra words actually detract from meaning.
- Think of a report as a big string of visuals, linked together by narrative sentences.
- Graphs, Figures, Tables, and Equations are all worthy of their own line.
- Avoid showing actual calculations in the body of the report—they are difficult to understand. Keep everything in variable format, and show numerical calculations in the appendix.
- Some instructors require more rigorously formatted reports; Check with them if you have any questions.

C Assessment Criteria

Lab Report Writing Checklist

- ☐ **Cover Page**
- ☐ **Abstract** gives a quick, complete summary of the experiment and its conclusions. Less than 400 words.
- ☐ **Table of Contents**
- ☐ **Introduction** provides background and theory for the experiment; shows what the experiment will find and why it is needed. States DQ.
- ☐ **Method** gives a complete description of the apparatus, equipment, and procedure which was followed in the experiment.
- ☐ **Results** describe the data obtained when the method was performed; shows uncertainties.
- ☐ **Discussion** is your interpretation of the results and describes them like a story. Answers DQ.
- ☐ **References**
- ☐ **Appendix**

The Big Question

Do you provide a clear & concise representation of your work?