Newton's Law of Cooling

Introduction

A hot object in contact with a cooler environment loses heat by forced convection. The rate at which heat is lost depends on a number of factors, including the difference between the object's temperature and that of its surroundings. Mathematically, this relationship is known as Newton's Law of Cooling and is expressed as

$$\frac{dT(t)}{dt} = -\kappa \left[T(t) - T_s\right]$$

where $T(t)$ is the object's temperature at time t, T_s is the temperature of the surroundings, and κ is a constant whose value depends upon the object's properties.

This form of Newton's law is hard to interpret as generally humans are not particularly adept at visualizing a differential equation. If we integrate the equation, however, we see easily that temperature decreases exponentially with time

$$T(t) = T_s + (T_0 - T_s)\, e^{-\kappa t}$$

where T_0 is the object's original temperature. In this experiment you will examine the validity of Newton's law for the cooling of a metallic temperature probe.

Skills Emphasized In This Lab

By completing this lab you will become more comfortable with:

- using the LabQuest Mini interface and LoggerPro software to collect and analyze data
- using a regression analysis to fit a theoretical equation to experimental data
- preparing useful figures and tables for reporting data
- communicating the results and conclusions of your work to others through a written report

##Preparing for Lab

Review the essays "Using Tables and Figures to Present Data" and "The Mathematical Modeling of Experimental Data," which are available on the course's website, and complete the appropriate sections of your electronic notebook before coming to lab.

Procedure

Begin by heating approximately 500 mL of deionized water to a temperature between 50°C and 100°C using a hotplote; the actual volume of water is not important. Connect the LabQuest Mini interface to a computer and attach two temperature probes to analog ports. Set your data acquisition parameters for a time-based experiment lasting ten minutes with a sampling rate of 20 points per minute.

When the temperature of the water in your beaker is within the desired range, place your two temperature probes in the water and allow them to equilibrate for at least one minute. Remove the probes, wipe off any residual water with a Kimwipe, and suspend the probes in the air so that they are not close to your hotplate and so that they are not close to each other. Once your probes are positioned, initiate data collection. When data collection is complete be sure to store your data before you continue with the next trial. Repeat this procedure for a minimum of five trials. ***Do not try to begin these trials at the same initial temperature***; in fact, it is best if you have a range of initial temperatures between 50°C and 100°C.

Data Analysis

Analyze the data for each trial and for each probe by fitting a suitable equation to the data, determining values for T_0, for T_s, and for κ.

Cautions

There are no serious cautions for this lab other than using care when handling hot water.

Waste Disposal

This is easy – it's just water!

Lab Report

For this report, focus on the ***results and conclusions section only***, paying particular attention to developing a narrative that uses tables and figures to summarize your data, that clearly analyzes your results, and that reaches clearly stated conclusions. Be sure to review the guidelines for preparing reports and the sample report, both available on the course's website.

Of particular interest is your determination of values for T_0, T_s, and κ. At a minimum, your report should address the following questions: What are the expected (theoretical) values for these variables or are their expected values unknown? If expected values for T_0, T_s, and κ are known, how accurate are your experimental results? How reproducible are your results for each variable and is this reproducibility (or lack or reproducibility) expected? How similar are your results for the two probes and is this similarity (or lack or similarity) expected? Is Newton's Law obeyed for the cooling of a hot probe and, if not, can you explain why? It might help to do some research on Newton's law, particularly with respect to its limitations and/or assumptions. Be sure to define Newton's law and its variables at the beginning of your report. Limit this report to approximately 3–5 pages of double-spaced text, tables, and figures.

Working together, prepare a draft of your report and then, after receiving feedback on this draft, prepare a final report. Deadlines are listed on the course's website.