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 we are not particularly adept at visualizing a differential equation. Integrating the equation, however, shows us 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 interface and LoggerPro software to collect and analyze data
- using a regression analysis to fit a theoretical equation to experimental data
- preparing useful figures for reporting data
- communicating the results and conclusions of your work to others through a written report

Preparing for Lab

Review the essays "Presenting Scientific Data and Results in Figures and Tables" and "The Mathematical Modeling of Experimental Data," which are included in the lab manual, and "Using the LabQuest 2 to Collect Data," the link for which is on the course's website, and complete the appropriate sections of your electronic notebook before coming to lab.

Procedure

Begin by heating 500 mL of deionized water to a temperature between 50°C and 100°C. Turn on the LabQuest 2 interface and attach two temperature probes. Set your data acquisition parameters for a time-based experiment lasting five minutes with a sampling rate of 30 points per minute.

When 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, suspend the probes in the air using a single stand and separate clamps to keep them well apart from each other, and 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 for each probe.

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 by fitting a suitable equation, determining values for T_0, T_s, and for κ for each probe.

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, you will 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 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? 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 that your narrative defines Newton's law and its variables. Limit this report to approximately 3–4 pages of double-spaced text, not counting space used for figures or tables.

After discussing your results as a group, choose one group member to prepare an initial draft and, after receiving edits from the other group members, prepare a final draft. The final draft is due by 4:00 pm on Tuesday, February 14th; this is a firm deadline. Comments on your final draft will be shared with you in lab on Thursday, February 16th. Your final report, which is prepared as a group, is due on Thursday, February 23rd.