Unit 4: Hooke’s Law

**Course-wide Learning Goals:**

By the end of the three-course intro lab sequence, students should be able to:

1. Collect data and revise the experimental procedure iteratively, reflectively, and responsively,
2. Evaluate the process and outcomes of an experiment quantitatively and qualitatively,
3. Extend the scope of an investigation whether or not results come out as expected,
4. Communicate the process and outcomes of an experiment, and
5. Conduct an experiment collaboratively and ethically.

### Objectives:

By the end of these activities, you should be able to:

* Evaluate the degree to which data agree or disagree with the Hooke’s law model for different elastic materials and configurations of elastic materials through fitting, comparing measurements, and graphs
* Decide how to use equipment to make measurements including the amount data to collect to obtain desirable uncertainty in measured values
* Deduce plausible explanations for instances when data and the model disagree including mistakes, equipment issues, or unexpected physical phenomena
* Propose and carry out follow-up investigations in light of results
* Present experimental designs, analyses, and results as arguments that are supported by and follow coherently from experimental data

**Pre-Lab Activity I (Due the day before your lab section meets during the week of Insert Date by 11:59pm):**

An experimenter has collected data of an elastic system and wants to determine whether the data is described by the Hooke’s law model (). Using quantitative methods (chi-squared, t’-scores, standard uncertainty in the mean, standard deviation, etc.), determine how consistent the data is with the model. Record your procedures and provide justification for your decisions. Discuss how you plan to improve your own measurements in this lab based on your analysis of the experimenter’s data.

Develop an Excel template that you can use during lab for the next two weeks to analyze your data. This template should automatically calculate the quantities that you're interested in obtaining when you input new data. If needed, reference the tutorials below for step-by-step instructions for a useful template.

**Pre-Lab Activity II (Due the day before your lab section meets during the week of Insert Date by 11:59pm):**

**Week 1: Encourage a fast pace and iteration, limit testing, etc. during this lab period. As an instructor, you should aim to encourage each group to extend their investigations so that they test at least a linear spring and a rubber band system by the end of the first lab session, including testing limitations. Push groups to investigate as many systems and improve measurements for each system. Students are welcome (and highly encouraged) to discuss their results with other groups.**

**At the end of the lab session, set aside 5-10 minutes for students to discuss within their groups a preliminary plan for what they might want to investigate during the second week. Groups should not feel committed to this plan but having this discussion is important.**

Week 1 Warm-Up (5 minutes):

Lead a whole class discussion about the quantitative methods that students used in the pre-lab. Ask the class to offer the quantitative methods they used and why they used that for this situation. Common issues that arise on the pre-lab include using the standard deviation rather than the standard uncertainty in the mean for the uncertainty in the force measurement and assuming the provided “k” will minimized chi-squared.

The data in the pre-lab is not “perfect”. The chi-squared value is approximately 9 and the t’ for measurements at the same position are often between 1 and 3 when stretching and relaxing the spring. For improvements, students might suggest: take more data, more carefully calibrate instruments to zero, make the distance between measurements smaller, etc.

1. Reflect on your findings from last week. What did or didn’t go as expected? How did you respond? What new questions do you have because of your investigation? What questions were you able and unable to answer?
2. Describe the system that you plan to test during the second week of the lab. Why is this system interesting? When do you expect Hooke’s law to be an appropriate model? When do you expect it to be an inappropriate model? How will you know? How will you test this?

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| **Activity I** |

Hooke’s law describes the relationship between force and distance for a linear stretched spring:

At your lab station you have a force probe, elastic materials, a metal reflector, a meter stick, and masses. Over the next two weeks, you will be designing experiments to test the validity of this model under various conditions for various systems.

During the first week, you should begin by testing the model using a single spring system and a rubber band system. After you have extensively tested these systems, extend your investigation to other systems and/or measuring methods.

Questions you may consider:

* Are there particular situations when Hooke’s law is or is not appropriate (e.g., consider varying spring constant, arrangement, position, time, etc.)?
* How do force measurements at the same positions compare when stretching versus relaxing?
* Are there modifications to Hooke’s law that you can make to account for limitations or approximations to the model?
* Why might your instructor request that you not to stretch each spring beyond a certain extent? (Ask your instructor whether you may overstretch a spring or whether there is a supply of springs that have been overstretched.)

Available systems include: single springs, springs in series, springs in parallel, other combinations of springs, springs with varying sizes and spring constants, and other materials. Bring in your own materials to test during the second week of this lab!

At the end of lab during the *second week*, your group will give a **two minute** presentation to the class about the most interesting finding from your investigations. Briefly explain your group’s experimental design, analysis methods, finding, and new questions generated by the finding. Use a whiteboard to sketch diagrams that may be helpful for conveying your finding to the class. All members of your group need to participate in this presentation.

When watching another groups’ presentation, find and write down what you would suggest they investigate next to extend their investigation. After groups have presented, your instructor will randomly select contributions from the rest of the class to provide suggestions for their next steps in investigations. **Be prepared to contribute!**

**Week 2:** Tell students that the goal for this lab is to come up with the most interesting and unique finding to share with the class. They are encouraged to discuss with other groups about their plans to reduce repetition and be extra creative. **Emphasize that a finding can be a null result, a tough experiment, or an unexpected result!**

**At some point during Week 1 or Week 2, pause students to have them look around the room and consider the sources of uncertainty from the variety of experimental set-ups that are present**. In this course, we emphasize using standard uncertainty in the mean to estimate the uncertainties in measurements because repeated measurements starting from the “baseline” should reasonably estimate uncertainty and account for sources of statistical uncertainty. However, in this experiment, if students do not “reset” their experiment for each trial, they will severely underestimate the size of the uncertainty in the force measurement and may introduce systematic uncertainties.

There are interesting systematic effects that students may not observe without conducting several trials where equipment is completely “reset”. For example, rubber bands slowly relax over the course of measurements. While this effect is (probably) not measurable if the experiment is quickly completed, it may be measurable for slower completion especially if the rubber band is overstretched.

Week 2 Warm-Up (10 minutes):

If there are major issues you observe during Week 1, address them as a whole class at the beginning of lab. It is important to skim through students’ Week 1 lab notes to determine common issues.

To facilitate unique findings, begin by having groups narrow down their plan for their investigation. Encourage groups to quickly check in (<1 minute per group) with other groups to find overlap in investigations. If groups have overlap, they should decide how to divide and conquer to limit identical investigations. Within 10 minutes of the beginning of class, students should be jumping into their investigations.

In-lab Guidance:

The model works well for most springs available to students in the lab, so as an instructor, encourage students to explore limitations to this model by investigating:

* Over-stretched springs (and “unbroken” springs)
* Non-linear orientations (e.g., three springs in a triangle)
* Elastic materials that are not springs (e.g., rubber bands)
* Other creative ideas that students may generate

Students may initially take the model to be "true" for any elastic material, so emphasize rigorous comparisons to the model for all materials.

Remind students to use skills developed in previous labs including:

* Accounting for and minimizing sources of uncertainty
* Determining distinguishability between measurements
* Using weighted least squares regression to compare the model and measurements

Encourage them to reference their previous work to recall how to set up spreadsheets, perform appropriate calculations, and minimize sources of uncertainty. This lab is a review of the semester’s data analysis techniques. Discuss the statistical tools in detail with groups (or the class) if students are having difficulties.

Students may complete this lab using either vertical or horizontal spring orientations.

* For horizontal orientations:
  + Encourage students to use the force probes for a force reading and a meter stick for the position reading
  + The Sonic Ranger can be used to track position but the program requires a different set up than the automatic settings – **Easier to avoid using the Sonic Ranger!**
* For vertical orientations:
  + Students may use hanging masses that provide a force calculable by treating the gravitational acceleration as a known constant
  + Students may use force probes too (see horizontal)

Hysteresis is observable with rubber bands in the kit. The thermodynamics properties of rubber bands make them interesting systems for students to explore (while not relevant to this lab, if you're interested in middle- and upper-division physics labs check out: [this](http://aapt.scitation.org/doi/abs/10.1119/1.4757908)). Stretching and relaxing the rubber band gives measurably different results (use t' to confirm!) if done quickly. However, hysteresis should not be observable when students are using**spring** configurations.