

✓ Stretchy things: Session 1

Run the code cell below to mount your Google Drive.

```
#start up
```

```
from google.colab import drive  
drive.mount('/content/drive')
```

In the code cell below, fill in the "..." with the directory information where your utilities file is located on your Drive.

```
%run "/content/drive/My Drive/.../utilities.ipynb"
```

Learning goals

By the end of this unit (Sessions 1 & 2), you should be able to:

- Implement practical strategies for mitigating bias when conducting experiments and analyzing data.
- Analyze data using least-squares fitting and residuals.
- Design high-precision experiments to test models, including identifying interesting variables to test, controlling variables, and reducing uncertainty.
- Manage time by conducting pilot experiments and plotting as you go.

✓ Group organization

We will form new groups for lab this week. To help you get to know each other, and to ensure effective collaboration and fairness, group members should discuss and write down the answers to the following questions in order to establish a "Partner Agreement."

Who are your Group Members and how do they prefer to be referred to (nicknames, pronouns, etc.)?

[Your group members' info here -- throughout this notebook keep your responses in boldface so we can easily distinguish your work from the main text of the lab manual]

Take turns having each group member share one thing about themselves (where you're from, what you like to do outside of class, etc.). Keep going around until you've found one thing you all have in common that you expect no other group will have in common and record it below.

[Your unique commonality]

Discuss with your partners what you're personally hoping to get out of this course. How do your goals compare? Discuss how you can support each other's goals. Can you agree on a collective goal for the group (e.g. to have fun, to provide a physics study group)? Establish your collective purpose and record it below.

[Your collective purpose]

To complete each lab a number of distinct tasks will need to be completed by individual group members or collaboratively by the group as a whole. These tasks include, but are not necessarily limited to, setting up equipment, collecting data, taking notes, and performing analysis, and managing the group. The tasks each of you spend the most time on will also likely be the ones you learn

performing analysis, and managing the group. The tasks each of you spend the most time on will also likely be the ones you learn the most about and grow the most in your ability to perform. How will you ensure each member has an equitable role and is able to be involved in all aspects of the work they're interested?

[Your group's plan here]

✓ Getting started

Hooke's law is a model that describes the relationship between force, F_y , and stretch distance, Δy , of a stretched spring: $F_y = -k\Delta y$. This model implies or assumes:

- A linear relationship ($k = \text{constant}$) between F_y and Δy over some range of values.
- Zero extension Δy corresponds to zero applied force F_y .
- There is no time, history, or other dependence in k or the measured values.

You will be designing experiments to test the validity of this model for a variety of systems under various conditions. We'll start by familiarizing ourselves with analysis methods by testing a single spring system.

Choose a spring to study for your first investigation.

[Describe your spring here - dimensions, material composition, anything else notable]

Briefly explore a few ways to measure the applied force. For example, you might use the gravitational force from an object with known mass hanging vertically from the end of your spring. Or you might use force probes to measure a horizontally applied force for some distance. Describe which method you will use for your investigation with a brief justification based on the sources of uncertainty, possible systematic effects, or more logistical constraints.

[Your method for measuring force and justification]

Design an investigation that uses linear least squares fitting tools to test whether or when Hooke's law applies to your system (i.e., is force on your object linearly proportional to its extension?). Include details about the major sources of uncertainty, your strategies for mitigating them, and how you quantified the uncertainty in your measurement.

[Your design here]

Start taking data by 30 mins in.

Carry out your investigation and summarize your data, analysis, and interpretations below. We've provided some code starters to get you going. There are multiple ways to set up the analysis, so we've chosen two approaches that are clear, but not efficient. You are welcome to take your own approach and PLEASE delete code for approaches that you decide not to use.

When copying code, please remember to edit comments, printouts, plot titles, axes labels, and any other artifacts of the code that need to be updated in order to align with whatever you are studying. Your code and code printouts should be comprehensible to anyone reading your notes.

Note about efficiency: You should be able to add data points to your code *as they are collected* so that you can look at your graph as you go. Do NOT wait to run the analysis until you have collected "all" your data. You may change what data you are collecting based on what you are seeing as you go.

Code to input your data

The manual is more open-ended than previous weeks. We are pulling away scaffolding. Remind them they still need to craft notes that are coherent and complete. Attention to details like sig figs, units, labels is important.

[] ↳ 3 cells hidden

Code to make a plot

Students are practicing fitting. Get them thinking about what matters: uncertainties, data spacing, data range.

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Code to find the line of best fit

You may have to check that the code they are using actually corresponds to their experimental method.

```
# Find the line of best fit
#If force is the dependent variable, use this code:
#Comment it out if not.
autoFit(x=ext, y=force, dy=force_unc, title="Force on a [object] stretched to various extensions", xaxis="Extens

#If extension is the dependent variable, use this code:
#Comment it out if not.
autoFit(x=force, y=ext, dy=ext_unc, title="Extension of a [object] due to various applied forces", xaxis="Force")
```

[Summarize your results, analysis, and interpretations here. Discuss the relevance of your results to the model you are testing, including how your data provides evidence for or against the assumptions of the model.]

Extending your investigation

Next, You will design your own investigation to test the Hooke's Law model under various conditions (i.e., push the limits of the model, as per Unit 1). For example, you might consider testing:

- the linearity of the relationship for different types (rubber band, hair tie, stretch fabric, etc) or arrangements of stretchy objects,
- the linearity of the relationship for extreme extensions or compressions (check with your TA about over-stretching springs),
- the assumption that there is no time or history dependence in k .

Articulate a question for your investigation and briefly explain how your current investigation inspired your new question.

[Your question and evidence-based justification here]

Design your experiment, analyze your data, reflect on your results, and iterate as appropriate. Document your process using text and code cells below. Be thorough and clear in your documentation. Don't forget units! Since you are designing your experiment, we are not providing specific prompts or questions to answer but your notes must include the following:

- description of the measurement method/apparatus
- discussion of sources of uncertainty
- data/plots
- discussion of analysis methods
- interpretation of results
- potential next steps

[Add text here]

#Create as many code cells and markdown cells as makes sense

By the end of the first session, you should have tested a simple spring system and at least one other system OR an assumption of Hooke's law. You should also have a brief outline for what you will do in the next session.

End of Session 1

Stretchy Things: Session 2

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Share your investigation

During the last 15 minutes of the lab session, you will present one graph of results to another group. While you show them the graph, you will briefly describe your experimental question, how you produced the data in the graph, and how you are interpreting the graph. When the other groups presents to you, you will be listening and evaluating their investigation so that you can ask questions and provide feedback.

Your presentation should not exceed 5 minutes (including time for questions from the other group).

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First session will be simple: Test a spring and one other object/idea.

Second session has room for creativity. You can provide ideas for systems/configurations to investigate: parallel/series springs, stretching/compressing/relaxing, twisting, deformation, etc.

There is code for quadratic fitting at the end of the notebook.

You can let students know about it if they express interest in fitting a non-linear function to their data.