

✓ Periods of a pendulum

Click on the Code Cell below, fill in the "..." as per the instruction and then run the code cell (shift-enter).

If you are having outsize struggles mounting your drive, try using a different browser. If that fails, ask your TA for help.

```
1 #start up
2 from google.colab import drive
3 drive.mount('/content/drive')
4
5
6 # Edit the file path below with the directory information where your utilities fi
7 %run "/content/drive/My Drive/Colab Notebooks/utilities.ipynb"
8
9
```

Learning goals

By the end of this 2-week unit, you should be able to:

- Design an experiment with sufficiently high precision to test a model, finding efficient and effective ways to reduce uncertainty.
- Identify and quantify sources of uncertainty in data.
- Compare pairs of measurements based on their uncertainties and use those comparisons to make appropriate inferences.
- Iterate on an experimental procedure to reduce *uncertainty*, test assumptions and claims, and extend the investigation to explore the phenomenon.

✓ Group organization

In this course you'll be working in groups on lab activities and related assignments. Negotiating group dynamics successfully is therefore an integral component of the course. 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 your reasons for taking this course and what you're personally hoping to get out of it. 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 ensure everyone learns something new, 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 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]

✓ **Session I: Understanding our measurements**

The focus of this unit is to evaluate whether the period of a pendulum depends on the amplitude of the swing. To test a model, scientists need to collect the highest quality data possible (or feasible).

By the end of today's lab, you will present to your TA your claim and evidence about which of several methods are the most precise ways to measure the period of a pendulum.

We will use those methods next week to test the proposed model.

A. Collect some data

Set up a pendulum apparatus with your group and make about ten measurements of the time it takes the pendulum to go through **a single period**. Utilize all group members to collect these data quickly (i.e., have everyone simultaneously measure the time with their own stopwatches).

In the space below, briefly describe your experimental design. How have you chosen to assemble the apparatus? What design choices did you make and why? What measures are you taking to reduce uncertainty in your measurement?

[Description of experimental design and technique here]

In the following Code cells, record your ten measurements for the period. Each measurement should be separated by a comma, for example, if you made the following three measurements: 10 s, 2 s, and 20 s, the code would be:

```
periods=np.array([10,2,20])
```

```
1 periods = np.array([...])
2
3 print("Measurements of the period of the pendulum from 10 single swings:")
4 print(periods)
```

✓ A. Evaluating data

The quality of a measurement can be evaluated based on its uncertainty. Uncertainty is unavoidable when making measurements, so we need to identify and estimate uncertainties as part of any measurement process.

We use the term **uncertainty** to refer to inevitable limitations in measurements associated with the methods or tools we use to make measurements.

Uncertainty should not be confused with **an error**--a mistake that should have been avoided or fixed. **Human error**, although commonly used, is incredibly vague. Don't use it. Instead, be specific. **If a human made an error, fix it.**

In the text cell below, list as many factors as you can that may have caused the variability in your measurements of the period of a pendulum. Roughly rank them based on how large you expect their impact to be on your measurements. Briefly explain your reasoning for the overall ranking.

[Your list here]

Run the code cell below to calculate the mean, standard deviation, and standard uncertainty in the mean of your measurements of the period from each amplitude.

```
1 mean_periods=np.mean(periods)
2 sd_periods=standard_deviation(periods)
3 su_periods=standard_unc_of_mean(periods)
4
5 print("Mean = " + str("%.2f" % mean_periods) + " s; Standard Deviation = " + str
```

Typical reaction time uncertainty is about 0.1 s and most stopwatches are precise to 0.01 s.

Is your standard deviation (the uncertainty in each measurement of the period) closer to the reaction time uncertainty or the stopwatch precision? Comment on what this might mean regarding the physical sources of uncertainty in your measurements (speculate!).

[Your answer here]

Design multiple ways you could minimize the uncertainty in your measurements **with the equipment available to you here in the lab**. Briefly explain your reasoning.

[Your answer here]

✓ B. Reducing uncertainty

Today, we will consider two methods for reducing measurement uncertainty: increasing the number of swings per trial and increasing the number of trials.

Why might measuring five consecutive pendulum swings in a single measurement trial reduce the uncertainty on your estimate of the period as compared to an estimate from five measurement trials of single swings?

[Your answer here]

How many repeated trials do you expect you would need to match the uncertainty from a single measurement of five consecutive swings? Provide either a guess or calculated prediction, with a brief explanation of your reasoning.

[Your prediction and explanation here]

Continuing the logic, measuring 20 or 50 consecutive pendulum swings should be even better than measuring 5 swings. One potential issue is that the amplitude of the swing will change over time.

How many consecutive swings do you expect would lead to a noticeable change in amplitude? Provide either a guess or calculated prediction, with a brief explanation of your reasoning.

[Your prediction and explanation here]

You should carry out two experiments to test these ideas.

✓ **Uncertainty Experiment 1**

First, design and implement a *quick* investigation to test your prediction for the number of repeated trials needed to match the uncertainty from a single measurement of five consecutive swings. Document your investigation and results.

[Your design here]

```
1 # your analysis code here: copy code from the activities above
```

[Your results and findings here]

✓ **Uncertainty Experiment 2**

Second, design and implement a *quick* investigation to determine at what number of consecutive swings the amplitude of the pendulum noticeably changes. Be sure you are specific about what you determine to be a noticeable change in amplitude. Document your investigation and results.

[Your design here]

```
1 # your analysis code here: copy and edit code from the activities above
```

[Your results and findings here]

✓ **C. Iterating and improving**

Let's keep going to find more ways to reduce the uncertainty of our measurements.

Carry out additional investigations to reduce the uncertainty in your measurements of the periods of your pendulum. You should be able to efficiently achieve an ultimate precision better than 0.005 s.

In the space below, jot down your methods and results, including:

- a clear description of how you measured the period, including any on-the-fly changes as you implemented the procedures,
- your raw data and calculated means, standard deviations, and standard uncertainties in the mean for your measurements of the period of the pendulum,
- a qualitative evaluation of the extent to which each of your methods affected the quality of your measurements, and
- suggestions for what you could do to reduce the uncertainty further.

[Your design here]

1 # your analysis code here: copy and edit code from the activities above

[Your results and findings here]

✓ Lab Checkout

By the end of the lab session, document below a claim about what you now believe to be the **most precise, accurate, and efficient method** and briefly summarize your evidence (from above) that supports your claim. Present your claim to your TA or (if you are out of time), they will look over these notes to evaluate your claim.

In the checkout, they will be looking for:

- Whether the claim is supported by evidence,
- Whether that evidence is sufficient, and
- Whether it is clear that you collected the data.

[Your claim and evidence here]

Save your notebook as PDF with all your answers to the questions, modified code cells, and output from each code cell visible.

You can also go to **File** > **Download** > **Download .ipynb**. This will download your notebook in .ipynb format. You can then use an online .ipynb to .pdf converter, such as [this one](#).

Make sure all your outputs are visible and nothing has been truncated or removed in your PDF before you submit it to Gradescope. If you need help with this, ask your TA for help.

Submit your notebook by uploading it to the Gradescope assignment titled **Lab 1.1 (S)**.