*Lab Handout*

# Lab 15. Simple Harmonic Motion and Rubber Bands: Under What Conditions Do Rubber Bands Obey Hooke's Law?

## Introduction

Harmonic oscillators are objects that move about an equilibrium point due to a restoring force. Two of the most common harmonic oscillators are pendulums and springs. Many objects that we encounter on a daily basis either contain a pendulum, such as a grandfather clock, or are a pendulum, such as the swings found on playgrounds. There are also many other objects that we use that incorporate springs. The shock absorbers found on cars, for example, are just large springs. Pendulums and springs, however, are not the only harmonic oscillators that are found in the world around us. For example, tire swings are a type of harmonic oscillator called a torsional oscillator because the restoring force from the rope causes the tire swing to twist back and forth (torsional motion is the motion of twisting). Another object that oscillates is a bungee jump ride (see Figure L15.1). When a person makes a bungee jump, he or she is attached to bungee cord and then dropped from a considerable height. That person then bounces up and down for the duration of the ride.

FIGURE L15.1

A bungee jump ride

Many oscillators obey the equations that describe simple harmonic motion. One of those equations is called Hooke's law, which states that the farther the oscillator is moved from its equilibrium point, the greater the restoring force on the oscillator. More specifically, the restoring force is directly proportional to the displacement the oscillator is from equilibrium. The equation for Hooke's law is $\mathbf{F} = -k\mathbf{x}$, where $\mathbf{F}$ is the restoring force, $\mathbf{x}$ is the displacement from equilibrium, and $k$ is a constant of proportionality. This equation includes a negative sign because the restoring force always acts in the direction opposite the direction of displacement. For example, if the bungee cord is pulled in the down direction, then the restoring force acts in the up direction.

It is important to note, however, that Hooke's law is not valid for all ranges of possible displacements. For example, if a spring is pulled too far from its equilibrium point by a disturbing force, the spring will actually deform and remain stretched out, instead of returning to the equilibrium position. This caveat to Hooke's law is particularly important for those who incorporate an oscillator into the design of an amusement park ride. If the displacement exceeds the allowable range, the restoring force can no longer return the oscillator to equilibrium. For a bungee ride, this issue can pose safety risks, because the riders would continue to fall toward the ground. It is therefore very important to know how much mass can be added to a bungee cord before it deforms or breaks. One way to determine the range of mass that can safely be added to a bungee is to use a smaller-scale model of the system to explore the relationship between mass and displacement. In addition, we can use a rubber band to approximate the behavior of a bungee cord because rubber bands are much smaller and much less expensive. This type of modeling allows engineers to determine parameters they will need to consider when doing tests using actual bungee cords.

## Your Task

Use what you know about forces, oscillation, systems and system models, and stability and change to design and carry out an investigation to determine the range of mass that can be added to a bungee cord so that it still obeys Hooke's law.

The guiding question of this investigation is, ***Under what conditions do rubber bands obey Hooke's law?***

### Materials

You may use any of the following materials during your investigation:

**Consumables**
- Rubber bands
- Tape

**Equipment**
- Safety glasses or goggles (required)
- Hanging mass set
- Paper clips
- Ruler
- Support stand
- Electronic or triple beam balance
- Stopwatch

If you have access to the following equipment, you may also consider using a video camera and a computer or tablet with video analysis software.

### Safety Precautions

Follow all normal lab safety rules. In addition, take the following safety precautions:

1. Wear sanitized safety glasses or goggles during lab setup, hands-on activity, and takedown.
2. Keep fingers and toes out of the way of moving objects.
3. Wash hands with soap and water after completing the lab.

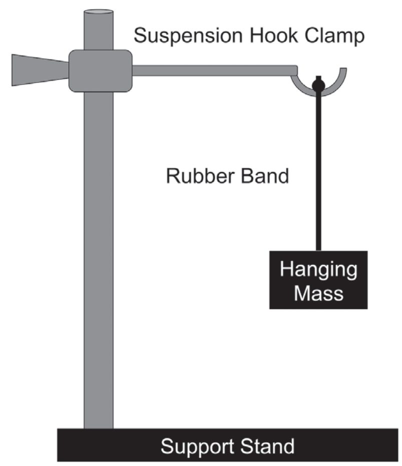
**Investigation Proposal Required?** ☐ Yes ☐ No

## Getting Started

To answer the guiding question, you will need to design and carry out an investigation to determine the range of mass that can be added to a rubber band so that it still obeys Hooke's law. Figure L15.2 illustrates how you can use the available equipment to study the motion of a mass–rubber band system. Before you can design your investigation, however, you must determine what type of data you need to collect, how you will collect it, and how you will analyze it.

FIGURE L15.2

**One way to examine the motion of the mass–rubber band system using the available equipment**




To determine *what type of data you need to collect,* think about the following questions:

- What are the boundaries and components of the mass–rubber band system?
- How do the components of the system interact with each other?
- When is this system stable, and under which conditions does it change?
- How could you keep track of changes in this system quantitatively?
- How will you measure the motion of the hanging mass?
- What are the independent variables and the dependent variables for each experiment?

To determine *how you will collect the data,* think about the following questions:

- What other factors will you need to control during each experiment?
- What scale or scales should you use when you take your measurements?
- How will you make sure that your data are of high quality (i.e., how will you reduce error)?
- How will you keep track of and organize the data you collect?

To determine *how you will analyze the data,* think about the following questions:

- What types of patterns might you look for as you analyze your data?
- What type of table or graph could you create to help make sense of your data?
- How will you model the system to indicate under what parameters the harmonic motion is stable?

## Connections to the Nature of Scientific Knowledge and Scientific Inquiry

As you work through your investigation, you may want to consider

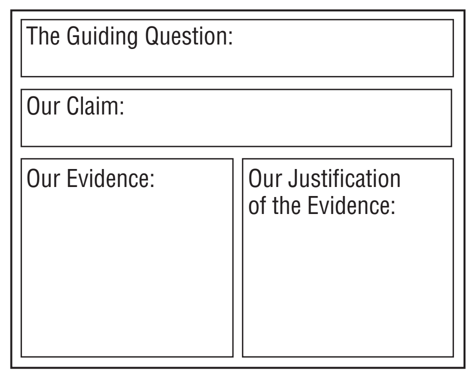
- how the culture of science, societal needs, and current events influence the work of scientists; and
- the role that imagination and creativity play in scientific research.

## Initial Argument

Once your group has finished collecting and analyzing your data, your group will need to develop an initial argument. Your initial argument needs to include a claim, evidence to support your claim, and a justification of the evidence. The *claim* is your group's answer to the guiding question. The *evidence* is an analysis and interpretation of your data. Finally, the *justification* of the evidence is why your group thinks the evidence matters. The justification of the evidence is important because scientists can use different kinds of evidence to support their claims. Your group will create your initial argument on a whiteboard. Your whiteboard should include all the information shown in Figure L15.3.

**FIGURE L15.3**

**Argument presentation on a whiteboard**




## Argumentation Session

The argumentation session allows all of the groups to share their arguments. One or two members of each group will stay at the lab station to share that group's argument, while the other members of the group go to the other lab stations to listen to and critique the other arguments. This is similar to what scientists do when they propose, support, evaluate, and refine new ideas during a poster session at a conference. If you are presenting your group's argument, your goal is to share your ideas and answer questions. You should also keep a record of the critiques and suggestions made by your classmates so you can use this feedback to make your initial argument stronger. You can keep track of specific critiques and suggestions for improvement that your classmates mention in the space below.

*Critiques about our initial argument and suggestions for improvement:*

If you are critiquing your classmates' arguments, your goal is to look for mistakes in their arguments and offer suggestions for improvement so these mistakes can be fixed. You should look for ways to make your initial argument stronger by looking for things that the other groups did well. You can keep track of interesting ideas that you see and hear during the argumentation in the space below. You can also use this space to keep track of any questions that you will need to discuss with your team.

*Interesting ideas from other groups or questions to take back to my group:*

Once the argumentation session is complete, you will have a chance to meet with your group and revise your initial argument. Your group might need to gather more data or design a way to test one or more alternative claims as part of this process. Remember, your goal at this stage of the investigation is to develop the best argument possible.

## Report

Once you have completed your research, you will need to prepare an *investigation report* that consists of three sections. Each section should provide an answer to the following questions:

1. What question were you trying to answer and why?
2. What did you do to answer your question and why?
3. What is your argument?

Your report should answer these questions in two pages or less. This report must be typed, and any diagrams, figures, or tables should be embedded into the document. Be sure to write in a persuasive style; you are trying to convince others that your claim is acceptable or valid!