# Hooke's Law

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## Lab Objectives

After the first week's experiment, students will be able to:

- Describe in words from their experiences how the force applied by a spring relates to the spring's extension
- Relate their experiment to a class discussion of Hooke's law
- Discuss relative merits of several methods of measuring force

After the second week's experiment, students will be able to:

- Apply their understanding of Hooke's law to noncanonical situations
- Interpret a graph that does not represent a simple mathematical function
- Explain the limits of the validity of Hooke's law

## Why Use This Lab in the AP Physics Course?

Through their own analysis, students will develop a conceptual understanding of the meaning of the "spring constant" for when Hooke's law ($F = kx$) is introduced in class. A student's personal, tactile experience with springs works better for this goal than any simple demonstration. That the student also gains some experience working with laboratory equipment and designing an experiment is a major side benefit.

## Correlation to the Topic Outline in the Course Description

I.B. Newton's laws of motion, p. 16
I.F.2. Mass on a spring, p. 17
Experimental situations, p. 19

## Online/Textbook Resources

The Web site www.newton.dep.anl.gov/askasci/phy00/phy00525.htm gives an interesting extension of the rubber band experiment to include effects of temperature and wetness.

A basic introduction to Hooke's law and elasticity is given in most AP-level textbooks; see, for example, *Physics* by Douglas C. Giancoli, chapters 6-4 and 9-6.

## Introduction

Hooke's law states that the force applied by a spring, *F,* relates linearly to the spring's displacement from equilibrium, *x*. Mathematically, Hooke's law is written as $F = kx$.[1] The variable *k* can be thought of mathematically as the proportionality constant between force and displacement, or as the slope of a force versus displacement graph. Physically, *k* provides a measure of a spring's stiffness. The variable *k* is referred to as the "spring constant," because *k* takes on a unique value for each spring.

Though usually applied to springs, Hooke's law is valid to one extent or another for many systems in which a "restoring force" is present. A restoring force simply means that an object experiences a force directed toward an equilibrium position. The force of a slightly bent metal strip, the force a spider web applies when catching an insect, and the force of a stretched rubber band all are restoring forces.

## Group Size

This experiment should be done in small groups, preferably of no more than two people.

## Lab Length

This sequence of two short experiments is designed to occur over the course of two lab periods, separated by about a week. The first experiment can easily be finished in an 80-90 minute period, and provides an excellent basis for the introduction of Hooke's law in class. The second experiment can be performed very quickly, but the write-up may need to be assigned as homework.

## Preparation and Prep Time

It is important to the objectives of the experiment that the *students* do all of the setup. Teacher preparation consists of obtaining a variety of springs and rubber bands, and making sure that force-measuring equipment is available and working.

## Materials and Equipment

- Enough springs and rubber bands for each group to have one of each. At least three different varieties of springs and rubber bands should be provided.
- Rulers and meter sticks
- Equipment to measure force:
    - Spring scales of various ranges

[1] In most texts, Hooke's law is written as $F = -kx$. The negative sign indicates that the direction of the force is always toward equilibrium, opposite the spring's displacement; see the next paragraph for a brief discussion.

    - Hooked or hanging weights
    - Electronic force probe, such as for use with Vernier's Lab Pro
- Graph paper

## Suppliers

Springs can often be salvaged; but they are available in most major science catalogs for purchase, as are spring scales and hanging weights. Rubber bands can be found at grocery or office supply stores. Vernier has force probes available for purchase at www.vernier.com.

## Safety and Disposal

Assuming common sense lab protocols (i.e., no shooting rubber bands in each others' eyes!), the only safety issue comes when the springs or rubber bands are stretched near their structural limit. At that point safety goggles are useful.

## Teaching Tips

In the first week, using the spring:

- There is almost no need to provide specific advice about procedure. It is far more valuable, especially in an experiment this basic, to allow the students to figure out how to measure force on their own or from each other. Encouraging collaboration is more effective than giving instruction.
- Similarly, students will likely ask for specifics such as the scale of the graph, or the range of forces and displacements. The only advice I usually provide, other than the stated requirements in the assignment, is to check out the range before starting: apply the largest force you're likely to use, and find out how far the spring stretches under this force. Then a scale for the graph can be determined.
- Students will always ask, "How much data do I need?" They need enough to convince any reasonable person beyond a doubt that the graph makes (in this case) a line.
- You may want to double-check the students' units. While both N/m and N/cm are valid units for the spring constant, it will confuse the comparisons between groups if units are not standardized. Be sure that either everyone's slope is stated in newtons per meter, or they are aware of the necessary conversions.

In the second week, using the rubber band:

- It's best not to give much guidance at all until a group has made a force-displacement graph. You may want to let them know that they are not bound to use the same force-measuring procedure they did with the spring.

- The force-displacement graph should look like two or three line segments with clearly different slopes. If a group's graph looks like a single line, they should measure forces for a wider range of displacements.
- Students will need guidance toward a correct analysis. They will want to create a simple mathematical function to describe their graph. That won't work well here. The simplest interpretation is that the rubber band obeys Hooke's law only for specific ranges of displacement, represented on the graph by the line segments with different slopes. For small displacements, the rubber band has a large spring constant; for the next larger range of displacements, the spring constant is smaller. Ideally, students can state the spring constant and displacement ranges quantitatively by taking the slope of each line segment, as shown in the sample data below.

## Sample Data

The force versus displacement graph for a spring should be inarguably linear. Spring constants for springs used in my classes range from about 5 N/m for a light spring that supports a PASCO dynamics cart in harmonic motion demonstrations, to about 30 N/m for a stiffer spring obtained from science supply houses.

The effective spring constant for a rubber band varies widely with the type of rubber band used. However, every rubber band I have used in class has three distinct regions in which the behavior is linear. One example of student-obtained data:

| **Displacement of rubber band** | **Spring constant** |
|---|---|
| 0-15 cm | 16 N/m |
| 15-50 cm | 14 N/m |
| 50-60 cm | 45 N/m |

## Sample Discussion Question Answers

1. Describe in words what the spring constant tells you about a spring. Include specific reference to other groups' springs (and their spring constants) in your discussion.

   The spring constant indicates the stiffness of the spring. The higher the spring constant (in units of newtons per meter), the stiffer the spring. Our spring's spring constant was 30 ± 2 N/m. Jessica's spring looked very similar to ours; so it is reasonable that she measured a similar constant of 28 ± 1 N/m. David's spring was much looser than ours. It stretched out very easily. Thus, it makes sense that he measured a much smaller spring constant of only 8 ± 1 N/m.

2. In an automobile's (or a train's) suspension, the wheel assembly is connected to the passenger compartment using several springs. You may even have seen these springs before. Comment on how the spring constant of an auto spring compares to the spring constant you measured today.

   A car is far heavier than any of the weights we used in lab today; yet the car's springs cannot compress more than a few centimeters. This indicates that the spring constant (in essence, the force applied to the spring divided by the spring's displacement) will be much, much larger than 30 N/m for a car spring. This is reasonable because the springs that I have seen in a car's suspension are incredibly stiff -- while we could easily stretch our lab spring a foot or more with one hand, a car's spring is not so easily moved.

## Assessment

The first experiment is worth 10 points. I print up this sheet, fill it out, and tape it into each lab book.

__ 1 point: Experiment is performed carefully and effectively.
__ 2 points: A graph is made which is useful for determining the spring constant.
__ 1 point: Graph contains clear labels and units.
__ 2 points: Slope is calculated properly from an appropriate best-fit line.
__ 3 points: Analysis question #1
__ 1 point: Analysis question # 2

**__ Total out of 10 points**

I grade the write-up from the second experiment in more detail. Students receive the sheet below, with my comments and the scores.

(1) **Experimental Design -- 10 Points**

- Did you use proper labels and units on your graphs and on all data?
- Did you use the proper number of significant figures?
- Did you carry out the experiment carefully and effectively?
- Did you include a useful diagram showing the experimental setup?

**Score** ______

(2) **Analysis -- 10 Points**

- Did you give a correct explanation of how a rubber band obeys Hooke's law?
- Did you support your explanation with quantitative information?
- Did you draw no inappropriate conclusions?

**Score** ______

(3) **Writing -- 10 Points.** Was your report:

- organized?
- easily comprehensible?
- concise, without extraneous information?

**Score** ______

**Total Score:** _____