Lesson Title	Elastic Deformation of Materials: An Investigation of Hooke's Law
Length of Lesson	1.5 hours
Created By	Justin Warren
Subject	Physics
Grade Level	11-12
State Standards	Physics: 1 c, d, f; 3 a, b
DOK Level	DOK 2
DOK Application	Cause/Effect, Make Observations, Interpret
National Standards	9-12: B
Graduate Research Element	Deforming materials through hypervelocity impact and characterizing that deformation

Student Learning Goal:
Students will investigate and quantify a phenomenon they intuitively understand: a mechanical load applied to an object or structure will cause a deformation of that object or structure. They will conduct three studies: demonstrate Hooke's Law as it applies to linear springs and examine both axial and torsional deformation of a solid specimen. In this way they will make the connection between loading and deformation.

Physics: 3. Develop an understanding of concepts related to work and energy: (a) Explain and apply the conservation of energy and momentum; (b) Analyze real-world applications to draw conclusions about mechanical potential energy (the energy of configuration) - Concept of conservation of energy with simple examples.

National Science Education Standards of Content 9-12
B (Physical): Conservation of energy and the increase in disorder: All energy can be considered to be either kinetic energy, which is the energy of motion; potential energy, which depends on relative position; or energy contained by a field, such as electromagnetic waves.

Materials Needed (supplies, hand-outs, resources):
Vertical and horizontal boom with boom clamps, linear spring, weight hook platform and weight set, ruler, tension loading apparatus (supporting frame, adjustable ruler measurement, fixed support, loading pin and container) tensile specimen (Teflon is good, but you can use other materials, just search for a material with a very low modulus of elasticity so that a relatively small amount of weight will produce a visible lengthening of the test section, something with a high modulus such as steel would require hundreds or thousands of pounds of force to produce visible deformations), torsional loading apparatus (rear and frontal tubular support, adjustable angular measurement scale, detachable loading arm, loading container), torsional specimen (again, Teflon is good, but you can use other materials as long as they have a very low modulus of rigidity), also

see the class handout "INSPIRE_Warren_06_29_12_Handout" under the Warren Supplementals folder which would be given to the students when class starts

Lesson Performance Task/Assessment:

Part 1: Demonstration of Hooke's Law:

In the first activity, students will hang a spring from a desk boom and affix the ruler so that the length of the unstretched spring can be measured (from the top coil to the bottom coil not including the hooks). Then weights of various values will be hung on the spring. The length of the spring will be recorded after each weight is added. The original length will then be subtracted from these values to determine the changes in length associated with each weight. A plot will then be produced with weight as the y-axis and change in spring length as the x-axis. This will produce a linear plot whose slope will be the spring constant of the spring under investigation. Figure 1 shows the spring constant activity fully set up and with some weights already hanging from the spring.

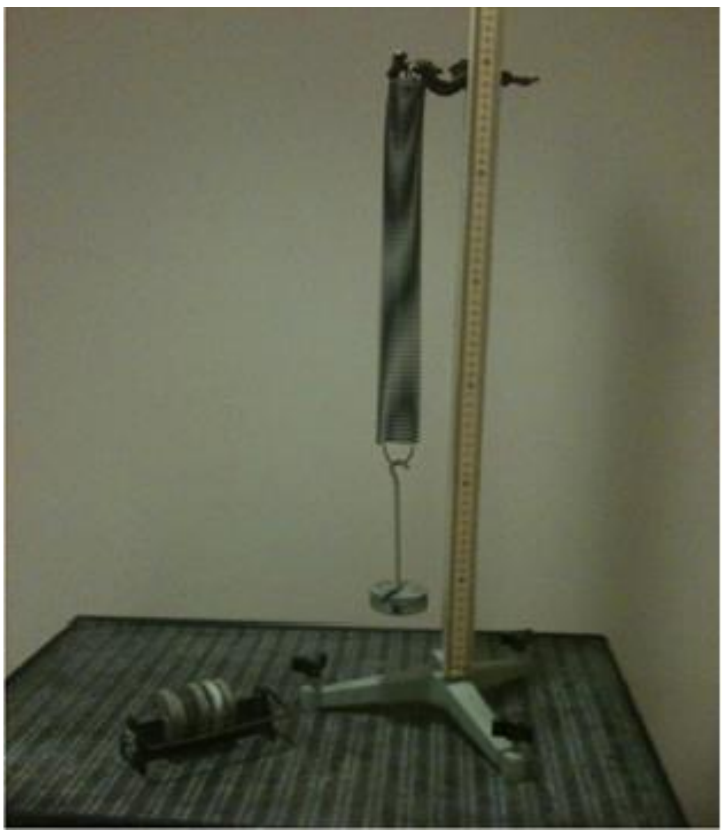


Figure 1. Spring constant activity

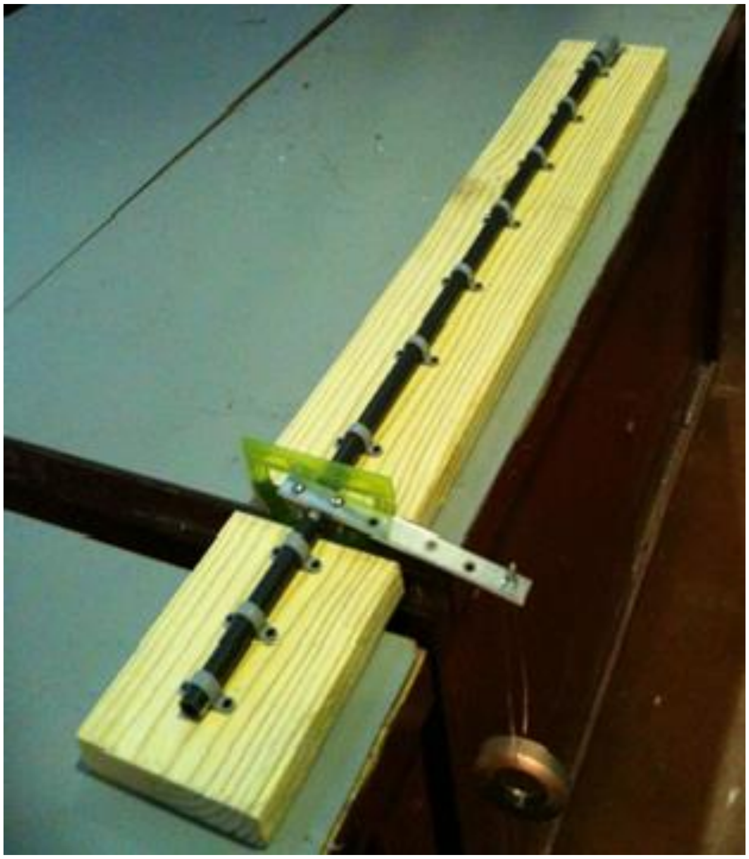
Part 2: Axial Deformation

First, the cross sectional area of the tensile specimen will be measured, either by measuring the diameter and using the area of a circle for cylindrical specimens, or by multiplying the depth and width of the cross section for rectangular specimens. The specimen will be inserted into the tension test apparatus by inserting the ends into the friction grips and evenly tightening the three sets of bolts on each. After inserting the specimen, the original length of specimen from the bottom of the upper grip and the top of the lower grip should be measured and recorded. Weights will then be hung inside the loading container, and the specimen will lengthen slightly after each weight is added. The new length of the test section will be measured. Then the original length is subtracted from each new length to determine the change in lengths similar to what was done in the spring constant activity. The student will convert the weight and change in length data to the equivalent normal stresses and normal strains. See the supplementary handout given to the student for explanations of how to calculate stresses and strains. A normal stress-strain diagram will then be plotted with normal stress on the y-axis and normal strain on the x-axis. This should be a linear plot from which the student will determine the modulus of elasticity of the test specimen by calculating the slope. This is again similar to determining the spring constant in the first activity. Figure 2 shows a circular rod tension test specimen inside the tension test frame with weights hung from the lower friction grip.

Figure 2. Tension test frame

Part 3: Torsional Deformation

The torsional specimen will be placed inside the torsional test frame. The specimen is first slid into the long frame through the protractor, and fixed into the friction grip on the opposite end by evenly tightening the clamp restraint bolts. Weights will be hung from the loading arm as shown in Figure 2, and the angular deformation will be recorded after each weight addition using the protractor attached to the torsion test frame. The student will then convert these weight and angular deformation data to the equivalent shear stress and shear strain, similar to the approach taken for the analysis of axial deformation. The student will then plot a shear stress-strain diagram with the shear stress as the y-axis and the shear strain as the x-axis. This should be a linear plot from which the students will calculate the slope. This slope value will be the modulus of rigidity. It must be emphasized that the specimen is not to be permanently deformed by adding excessive weights.



Lesson Relevance to Performance Task and Students:

The student will link loading to deformation and consider what effects this has to real world applications. The student will also gain experience with the physical representations of stress and strain.

Anticipatory Set/Capture Interest:
The class will be shown a YouTube video of a quasistatic tension test to failure (the specimen is very slowly pulled apart until it breaks into two pieces) of a metallic specimen similar to the following link: http://www.youtube.com/watch?v=67fSwIjYJ-E. They will be asked to give their opinions of what will happen to the specimen during loading and will also be instructed to pay close attention to the necking process in which the specimen dramatically narrows just before breaking.

Guided Practice:
The instructor will make clear that the lab will deal with the relationship between load and deformation. The instructor will speak briefly on the structure of the lab in relation to the anticipatory set and also on what ideas to keep in mind.

Independent Practice:
The instructor will hand out instruction sheets containing descriptions of force, deformation, stress, and strain as well as the pertinent calculations involved. The student will set up the spring boom on their own, but the tension and torsional loading apparatus will be preassembled. During the lab the instructor will move amongst the groups fielding questions, explaining phenomenon, and asking provocative questions.

Remediation and/or Enrichment:
The instructor will address remediation concerns with student/groups individually during the lab. It is expected that the relatively simple relationships involved in this lab will require a very limited amount of remediation.

The enrichment activity will be to derive the governing differential equation for both axial and torsional deformation.

Check(s) for Understanding:
The student will be required to discuss what implications the load/deformation relationship has for real world applications.

Closure:
Following the lab, the instructor will discuss complete stress-strain diagrams as well as their importance in engineering applications. My research, as well as most of solid mechanics, focuses on describing deformation. This lab was a very short introduction to a topic that could fill a lifetime of work. The problems become more and more complicated as assumptions are taken away, but more importantly when the geometries,

material response, loadings, etc become non-linear. The instructor will show other YouTube videos of materials testing if time permits.

Here are some provocative questions to ask the students after the lesson:

- What would happen to a tension test specimen if it was loaded in compression? How would the compressive stress strain diagram differ from the tensile stress strain diagram?
- Based on what you know of atomic theory, what is happening to the individual atoms/molecules as a test specimen is deformed?
- Why is it important to constrain the test specimens to one degree of freedom like we did in the tensile and torsion tests?

Possible Alternate Subject Integrations:
Calculation of the slope of a line given a data set, and also differential equations

Teacher Notes:
Make sure students do not permanently deform the specimens so that they can be reused. Maintain a focus throughout the lab that loading causes deformation and that relation can be described in scientific terms that are useful to scientists and engineers.

If time constraints become an issue, the third activity involving the torsional deformation of a specimen can be eliminated.