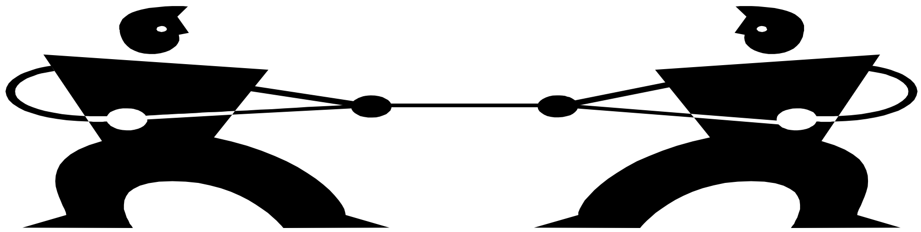
Cornell Center for Materials Research

Name ______________________ Hour ________ Date ________

"Can you handle the stress?"



"Are you under too much strain?"

Purpose: To determine the Young's modulus for four different materials in two different ways and compare the stiffness of the materials based upon this value.

Background on Elasticity:

Stretching of a Spring. If a vertically mounted rod, wire, or spring is supported rigidly at its upper end and weights are added to its lower end, the amount by which it is stretched is found to be directly proportional to the weight applied. This is known as **Hooke's Law**. The stretching of a spring due to an added **weight**, **W**, stretches the spring a **distance**, **x**. If a second equal weight is added, the total distance stretched will be twice that for the first one. If a third weight is added, the total distance stretched will be three times that for the first one, etc. To make an equation of this, we write, **W = kx**, where **k** is a constant. When the spring is stretched a **distance**, **x**, the spring itself exerts an upward **force**, **F**, equal but opposite in direction to **W**. For the spring, **F = -kx**, where the minus sign indicates that **x** and **F** are in opposite directions. This equation is referred to as **Hooke's Law**.

Stretching of a Wire or Rod. Because a wire or rod will not stretch very far before reaching the breaking point, one must, in order to check **Hooke's Law**, resort to some method of measuring extremely small changes in length. The amount the wire is stretched is directly proportional to the force applied, and if the weights are removed, the wire will return to its original length like the spring. This region of movement of the wire is called the **elastic region**. If weights are continually added, the forces applied will eventually become too great, and **Hooke's Law** will no longer hold as the elongation will increase too rapidly. The

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wire will no longer return to its original length if the weights are applied. The point at which **Hooke's Law** ceases to hold is called the **elastic limit**. When the wire is stretched beyond its elastic limit, it is considered to be in the **plastic region**, meaning that is does not return to its original length when the weight is removed. Eventually, the material reaches its **yield point**, beyond which it breaks. This gives an indication of the **strength** of the material.

Stress and Strain. When a force of any magnitude is applied to a solid body, the body becomes distorted. Whether the distortion is large or small, some portion of the body is moved with respect to some neighboring position. As a result of this displacement, atomic forces of attraction or repulsion set up restoring forces, which resist the alteration and tend to restore the body to its original shape. The greater the applied force, the greater will be the deformation, thereby setting up greater atomic restoring forces, which act to bring about equilibrium. It is common engineering practice to describe the restoring forces in a distorted body as a **stress** and to give to this term the quantitative definition of **force per unit area**. The actual deformation of the body produced by an applied force involves a change in geometrical form called **strain**. **Strain** is defined as a quantitative measure of deformation.

Stress (σ) is defined as, $\sigma = F / A$, where **F = force applied to the sample at any given instant** and **A = cross-sectional area of the sample**. **Strain (ε)** is defined as, $\varepsilon = \Delta l / l_0$, where **$\Delta l$ is the change in length (elongation)** and **l_0 the original length of the sample**. **Stress** has units of Pascals (N / m^2) and **strain** is dimensionless. The concept of a **stress** is clearly closely related to that of **pressure**.

Young's Modulus. In general, **Hooke's Law** states that **stress is proportional to strain**. In the **elastic region**, the **"stiffness" or "elastic modulus"** is the amount of stress required to produce a given amount of strain. **Stiffness** is described by **Young's modulus (E)**, which is equal to the ratio of the **stress** on an object to the **strain** the object undergoes. This can be written as the equation, $E = \sigma / \varepsilon$.

Bending. When a rod or beam is subjected to a force tending to bend it, the amount of bending is directly proportional to the force applied. In what is known as a **two-point test**, the rod or beam is clamped at one end and a downward **force**, **F**, is exerted at the other end. The material undergoes a **displacement**, **d**. In what is known as a **three-point test**, the rod or beam is supported at both ends and a downward **force**, **F**, is exerted at the middle. The material undergoes a **displacement**, **d**.

To see how stretching and compressing enter into the bending of a rod or beam, imagine the rod or beam divided into layers. In bending, the lower layers are

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stretched by varying amounts, while the upper layers are compressed. The bending of a rod or beam follows **Hooke's Law**. The bending **displacement**, **d**, is directly proportional to the applied bending **force**, **F**. The equations for each are shown below and involve the **Young's modulus (E)** as well as the **dimensions** of the rod or beam. In the case of a beam, the **width (w)** and **height (h)** of the beam are important. In the case of a rod, the **radius (r)** is important. The other important factor deals with the **length (L)**. However, this **length (L)** is either the distance from the support to the end of the rod or beam for the 2-point test or the distance between the supports for a 3-point test.

Equations:

2-point test for a beam: $d = 4FL^3 / Ewh^3$	3-point test for a beam: $d = FL^3 / 4Ewh^3$

Equipment:

Steel beam	**Meter stick**
Copper beam	**Vernier Caliper**
Garolite (fiberglass) beam	**Various Slotted Masses (100 g to 5000 g)**
Balsa wood beam	**Mass Hanger**
C Clamp	**Wire**

Procedure:

Students will be divided into groups of four. Each group will be given the above materials. The teacher will demonstrate the difference between a 2-point and a 3-point test. The students should work as a group to make appropriate measurements of their materials (**width and height**) and perform both kinds of tests on their materials being sure to make measurements of the setup (**length**). During these tests, students should vary the amount of **force** applied to the material and make appropriate measurements of the **displacement** of the material.

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Assessment:

Graphs:

- Make a graph of **displacement of the material (d)** on the y-axis and the **force applied to the material (F)** on the x-axis for each of your four materials.
- Draw a best fit line through the points and determine the slope of the line.
- Using the slope of the line and the equations given for the 2-point and 3-point tests, determine the **Young's modulus** for each of the materials.

Analysis:

- Rank your materials from most stiff to least stiff based upon your value for the **Young's modulus** for each.
- Calculate the percent error for each of your materials using the accepted value of the Young's modulus for each below.

Material	Young's modulus (N / m^2)
Balsa wood	1.50×10^{8}
Copper	1.25×10^{11}
Garolite (fiberglass)	1.70×10^{10}
Steel	1.92×10^{11}

Extensions:

- Devise an experiment to determine Young's modulus and yield strength for different metal wires.
- Bring in materials from home to be tested.
- Test unknown materials and use the Young's modulus to identify them.
- Test a material with different shapes other than a rectangular beam, such as a rod or a hollow material to prove Young's modulus remains the same.

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