• C.J. Overbeck Northwestern University • R.R. Palmer Beloit College • Marsh W. White The Pennsylvania State University

YOUNG'S MODULUS OF ELASTICITY DIRECT MEASUREMENT OF STRETCH WITH A MICROMETER SCREW AND A LEVEL

OBJECT: To determine Young's modulus of elasticity of a wire by stretching.

METHOD: Along vertical wire, securely fastened at its upper end, is stretched by attaching known weights. The extension, or stretch, for a given applied force as well as the cross section and the original length are measured. From these quantities and the applied force, Young's modulus of elasticity is calculated.

THEORY: Over a considerable range it is found by experiment that the deformation of a body produced by forces is proportional to the magnitude of these forces. This proportionality between deformation and applied forces is called Hooke's law and is the basis of the theory of elasticity. The value of the stress for which Hooke's law just ceases to hold is called the elastic limit of the substance. The elastic limit may also be defined as the magnitude of the applied stress which produces the maximum amount of recoverable deformation.

The fractional change in the dimensions of a body produced by a system of forces in equilibrium is called a strain.

Even within the limits of perfect elasticity, different bodies show distinct differences in their behavior. Some recover their form immediately after the removal of the force, while others, though they recover it ultimately, take considerable time to do so. This delay in recovering the original condition of the substance is called the elastic *after-effect*, or elastic lag.

When a wire is stretched beyond its elastic limit and its cross section is reduced, as in drawing through a die, its structure is broken down and the surface appears to be an amorphous layer of flowed material. This flowed layer becomes proportionately thicker with repeated drawings and the density, hardness and elasticity of the material are profoundly changed. For instance, when a wire of Swedish iron has its diameter reduced from 0.75mm to 0.10mm by repeated drawings, the breaking strength measured in force per unit area is *doubled.* Keeping in mind these changes, the student will not expect an exact check of his results for the modulus of elasticity with accepted values given in tables.

When a wire is stretched, there is not only a change in its length but also a much smaller change in its diameter. Young's modulus of elasticity *Y* takes into account only the change in length- the longitudinal strain which occurs. This strain is the change in length per unit length.

The longitudinal stress produced by the applied forces is measured in terms of force per unit area. Young's modulus is defined as the ratio of the longitudinal stress to the

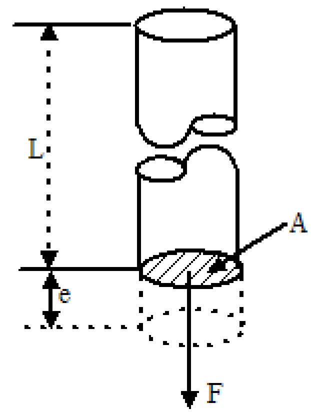

Fig. 1. Stress and strain involved in the stretching of a wire. The stress, which is the force per unit area, is F/A; the strain, which is the elongation per unit length, is e/L.

longitudinal strain.

If *L* represents the initial length of the wire (Fig.1), *r* its average radius, *e* the stretch produced by the weight of a mass *M*, then

$$\text{Young's modulus} = \frac{\text{stress}}{\text{strain}} = \frac{\text{force/area}}{\text{elongation/length}}$$

$$Y = \frac{Mg/\pi r^2}{e/L} = \frac{MgL}{\pi r^2 e} \qquad (1)$$

APPARATUS: In this experiment the stretch of the wire is measured directly by means of a micrometer screw. The apparatus is illustrated in Fig. 2. On a heavy tripod base provided with leveling screws are mounted two nickel-plated steel support rods 140cm long, with a yoke clamped to their upper ends. This yoke carries a chuck for supporting the wire to be tested. A weight hanger supports the load by means of which the tension is applied to the wire. Near its lower end the wire passes through a hole in an adjustable bridge or platform which is clamped to the support rods. The measuring apparatus (Fig. 3) consists of a level, pivoted on a chuck which tightly clamps the wire, with a micrometer screw at one end and a sensitive spirit level at the other. The chuck rides easily in a hole in the bridge. As weights are applied to load the wire, the extension tilts the lever so that adjustment of the micrometer screw must be made to bring the spirit level back to horizontal.

As auxiliary apparatus slotted kilogram weights, a micrometer caliper and a meter stick are needed.

PROCEDURE:

Experimental: In case it is necessary to install a wire in the apparatus, select a sample about two meters long as free from kinks and bends as possible. To ensure a fairly straight wire, clamp one end in a vise and, wrapping the other end about a stick of wood, give the wire one or two sharp jerks. Then place the wire between two flat sticks and, while pressing them tightly together, pull the wire through two or three times, giving the sticks a slight tilt while pulling. After the straightening process, cut off four or five inches from each end of the wire. Open the chuck in the yoke and also the one in the measuring device. Insert the chuck of the measuring device in the hole in the platform. Pass the wire through the chuck in the measuring device and upward through the chuck in the yoke, fastening it securely. Adjust the bridge so that there is at least a meter of wire between the two chucks, then close the lower chuck. Pass the bottom end of the wire three times around the hook of the weight hanger, bringing the end up under the turns of wire, and adjust the length so that the bottom of the hanger is about an inch above the base. Then hold the two wires firmly with the pliers about an inch above the top of the hanger and twist the hanger until the wires are tightly wrapped around each other. Cut off the loose end.

Fig. 2. Young's Modulus Apparatus shown in use.

The micrometer screw should be set near the lower end (zero) of the scale and the bridge adjusted so that the bubble is near the center of the level. Level the apparatus so that the lower chuck swings freely in the platform. In bringing the bubble to the center of the level, *to avoid backlash always turn the micrometer screw towards larger numbers on the head.*

Carefully place 10kg on the weight hanger, keeping one hand under the weight hanger as each weight is added and allowing the wire to take up each additional load slowly. Turn the micrometer screw until the bubble is centered in the level and read the scale and head, recording the reading in centimeters. Wait a full minute and see whether the bubble slowly moves under this load. If it does, remove 1kg and observe again. In this way find the maximum load, under 10kg, which is within the elastic limit. Remove this load and then carefully replace it twice, reading the scale and micrometer for this maximum load each time.

Remove all the weights and take a reading with the hanger alone. Then take a series of readings increasing the load in steps of 1kg up to the maximum. Take a second series of readings as the weights are removed. Measure with the meter stick the length of the wire from the under side of the upper chuck to the upper side of the lower chuck. With the micrometer calipers make ten determinations of the diameter of the wire at five different points along the wire, two measurements at right angles to each other at each point. Record these measurements, expressing the results in *centimeters*.

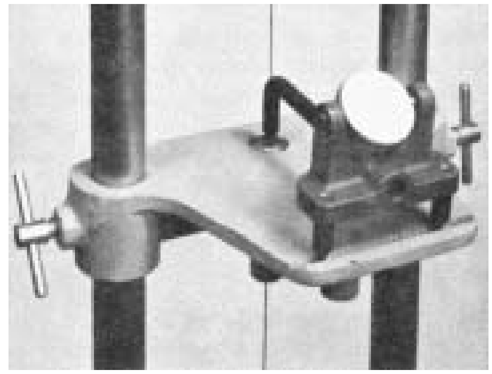

Fig. 3. Apparatus for measuring the stretch of a wire.

Interpretation of Data: Average the readings of the stretch for each load and make a graph to a large scale showing the total stretch as a function of the load. Draw the straight line which best represents the plotted points, disregarding if necessary the first one or two points. From this graph, compute the stretch in centimeters per thousand grams.

Calculate Young's modulus of elasticity using the data obtained and Eq. (1), in which M will have the value one thousand.

QUESTIONS: 1. What explanation could be given for the fact that the first one or two of the plotted points might not fit the line drawn?

2. The length of a wire 200cm long can be measured to an accuracy of ±1mm. If the diameter of the wire is 0.50mm, to what accuracy should the diameter be measured in order to produce the same error in the result?

3. Recalculate the value of the modulus using a value for the length 1mm greater than the one first used. Make a second calculation increasing the value assigned to the diameter of the wire 0.001cm. Which produces the greater change in the modulus?

4. How long a piece of wire, of the same material and cross section as used in this experiment, would it take if the stretch were to be exactly 1.5mm with a load of 5kg?