CENCO Physics Selective Experiments In Physics

• 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 SCALE AND VERNIER

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

METHOD: A long 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.

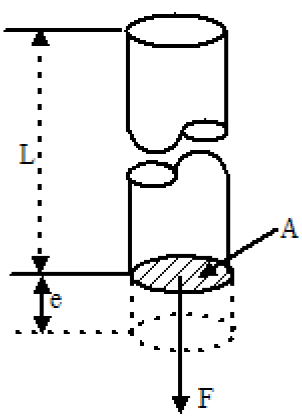

Fig. 1. Stress and strain involved in the stretching of a wire. The stress, which is the force per unit area, is F/A; the strain, which is the elongation per unit length, is e/L.

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 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 scale and vernier. The apparatus (Fig. 2) consists of a heavy wall bracket to which two wires of the same material are attached. The scale on which the elongations are measured is supported by the wire to be tested while the other wire supports the vernier behind which the scale moves as the load is varied. Both scale and vernier are independently adjust-able vertically and in angular position, and the vernier can, in addition, be adjusted with reference to its overlap on the scale. The auxiliary apparatus needed consists of two weight hangers, four slotted weights, a micrometer caliper and a meter stick.

PROCEDURE: Before putting new wires in the apparatus, first see that they are as free from kinks and bends as possible, otherwise the elongation due to straightening will be added to the elongation due to stretching. Make a smooth loop on the end of each wire, slip the loop under the plate around the screw, see that the wire is vertical, and tighten securely. Put on the empty weight hangers. Adjust the vernier for an overlap of about 2mm and set it at about the middle of the scale.

Fig. 2. Apparatus for determining Young's modulus using a scale and vernier.

As a limbering up exercise for the wire and a test to make sure that the elastic limit is not being exceeded, carefully read the scale and vernier. Then place the four weights, one after the other, on the weight hanger. In doing this, place one hand under the weight hanger and let the wire assume the added load slowly. Read the scale and vernier, making sure that the apparatus is not swaying sideways. Wait one minute and read the scale and vernier again. Carefully remove the weights, one at a time, and read the scale and vernier again.

Repeat the entire cycle of operations. If the readings with full load increase with the time and if the final readings are successively larger each time, the load has exceeded the elastic limit. If this is the case, then in place of four 2kg weights use four 1kg weights or even four 500gm weights, if necessary, in order to keep within the elastic limit of the wire.

Having determined a series of weights suitable for the wire, take a series of careful readings as follows: First read the scale and vernier with the hanger alone; this reading will be called the *zero* reading. Then add the weights one at a time, reading the scale and vernier each time a weight is added. Repeat the readings as the weights are taken off one at a time. Subtract the zero reading from the average reading for one, two, three and four weights and find the average stretch per weight. If the stretch for the first weight is larger than the stretch per weight for the succeeding values, this indicates a bend in the wire which is being straightened. In this case take the reading for the hanger plus one weight as the zero reading and calculate anew value of the stretch per weight.

Measure the diameter of the wire, in centimeters, at five different points along the wire with the micrometer calipers. At each point take two measurements of diameters that are at right angles to each other.

Record the name of the material of the wire and calculate its modulus of elasticity, using Eq. (1).

QUESTIONS: 1. Using the value of the modulus which has been calculated, determine the length of a wire of the same material and cross section which would stretch 1mm when a force of 2000 dynes is applied.

2. State two advantages secured by having the vernier carried by a similar wire instead of being supported by a separate clamp stand.

3. 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?

4. Assume that the length of the wire used in the experiment was measured with an error of 1mm. Calculate the percentage change in the modulus which would result. Compare this with the percentage change due to an error in the measurement of diameter of 0.01mm.