WST 08/28/94
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Experiment 1 – Measurement and Measurement Uncertainties

Objectives

To learn to read a vernier scale. To learn how uncertainties in measurements are translated into uncertainties in the results. To verify Hooke's Law for a spring.

Equipment

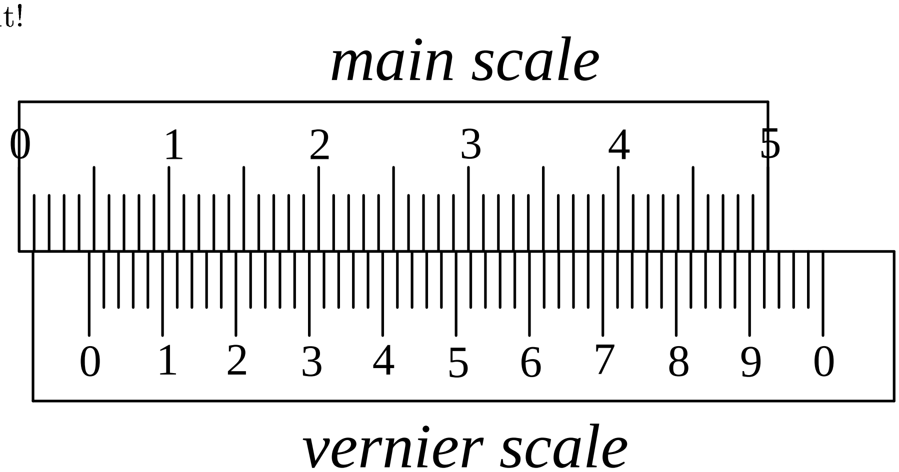
- Vernier caliper.
- Penny.
- Balance.
- Spring and weights.
- Meter stick.

I. Density Measurement

A. Using the vernier caliper, determine the diameter and thickness of your penny. In principle, the vernier scale allows you to determine these measurements to the nearest 1/50 mm (±0.002 cm).

How to read the vernier scale:

Many precision measuring instruments are equipped with a vernier scale which allow you to accurately interpolate between the markings on the main scale. Don't be scared by the length of these directions: actually reading a vernier scale is much easier than explaining how to read it!



- The Metric scale on the caliper consists of two parts, a "main" scale (in centimeters: you can tell since it says "cm" on the caliper) and a vernier scale below it (marked off in 1/50 mm subdivisions, this information is on the caliper as well).
- The left-most "0" on the vernier scale indicates which marking on the main scale applies. In the case illustrated, the "0" is just to the right of the 0.4 cm mark, so the distance being measured is between 0.4 cm and 0.5 cm.

- Next, the spacing between the marks is arranged so that the mark on the vernier scale which most-closely matches *any* mark on the main scale tells you what the next two digits in the distance are. (Sometimes two or three adjacent marks will match more-or-less equally well). In the drawing, the "66" mark lines up with one of the marks above it (the "64" and the "68" are also close), so the full distance is 0.466 cm.

diameter of penny	$\pm$
thickness of penny	$\pm$

B. Assuming that the penny is a flat cylinder, use the formula $V = \frac{1}{4}\pi d^2 h$ to compute the volume of the penny. In this formula, V represents the volume, d the diameter, and h the thickness of the penny.

Q1. Why is ± 0.002 cm probably an *underestimate* of the uncertainty in the thickness of the penny?

When two measurements are multiplied together, the fractional uncertainty of their product is simply the sum of the fractional uncertainty of the individual measurements. So for the volume calculation (δV is the uncertainty in the volume, δd is the uncertainty in the measured diameter, and δh is the uncertainty in the measured thickness),

$$\frac{\delta V}{V} = 2\frac{\delta d}{d} + \frac{\delta h}{h}.$$

(Since d is squared (multiplied by itself), we must count its fractional uncertainty twice).

C. Calculate the fractional uncertainty in the volume of the penny, and then the uncertainty in the volume (multiply the fractional uncertainty by V to get this).

volume of penny	$\pm$

D. Determine the mass of your penny using the balance. Be sure to record the uncertainty in your measurement.

mass of penny	$\pm$

Q2. What measurement could you do which would allow you to determine the mass of one penny but with a smaller uncertainty?

E. Calculate the density of the penny. Calculate the uncertainty in the density. Since the density ρ is the mass per unit volume, ($\rho = m/V$), the fractional uncertainty in the density is the sum of the fractional uncertainties in the mass and volume:

$$\frac{\delta\rho}{\rho} = \frac{\delta m}{m} + \frac{\delta V}{V}.$$

density of penny	$\pm$

Q3. Explain why it would have been a bad idea to have used a meter stick to determine the diameter and thickness of your penny. (Hint: Given that a meter stick can at best be read to the nearest ± 0.05 cm, what would be the fractional uncertainty of your density measurement?)

II. Hooke's Law

Hooke's Law says that if the elasticity limit is not reached, an object's extension is linearly proportional to the applied force:

$$F = kX,$$

where X is the extension (amount of stretching) of the object, F is the applied force, and k is the elastic constant.

A. Apply a series of weights to your spring and measure its extension. You may assume that calibration error of the weights is negligible. However, you should assign an error to the measurement of the extension. Record your data in the table below.

mass	applied force (= weight)	extension
		±
		±
		±
		±
		±
		±
		±
		±
		±

NOTE: To convert the mass of an object in kg to its weight in newtons, multiply by $9.8 \text{ m/s}^2 \equiv 9.8 \text{ N/kg}$.

B. Plot your data with the force on the horizontal axis and the extension on the vertical axis. Draw a best-fit straight line through the data and determine the slope of this line. Your measured value of the elastic constant is just the inverse of the slope:

$$k = \frac{1}{slope}.$$

[ASIDE: When plotting the relationship between two measured quantities, it is conventional to plot the independent variable (*i.e.* the "cause") along the horizontal axis and the dependent variable (*i.e.* the "effect") along the vertical axis. In this case, the extension of the spring is the result of the applied force. Since $X = F/k$, the slope of the plot measures $1/k$, rather than just k directly.]