

EXPERIMENT 1

Mass, Volume and Density

PURPOSE

1. To familiarize with basic measurement tools such as the vernier caliper, micrometer, and weighing balance.
2. To learn how to use the concepts of the significant figures, the experimental uncertainty (error) and some methods of error and data analysis in your experimental measurements.

EQUIPMENT

A steel ball, a rectangular aluminum block, a brass cylinder, a aluminum annular cylinder, vernier calipers, micrometer, balance.

THEORY

- **Least Count of an Instrument Scale**

The **Least Count** of an instrument is the smallest subdivision marked on its scale. This is the unit of the smallest reading that can be made without estimating.

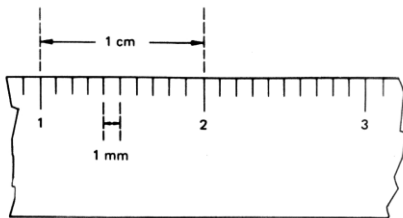


Figure 1 **Least count.**

Metersticks are commonly calibrated in centimeters (numbered major division) with a least count, or smallest marked subdivision, of millimeters.

- **The Vernier Caliper**

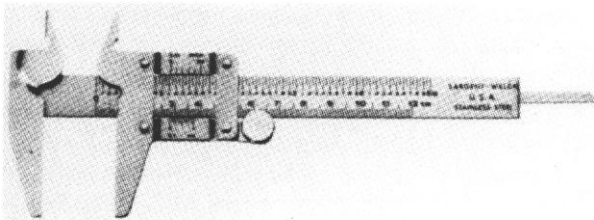


Figure 2 **The vernier caliper.**

The vernier caliper (Figure 2) consists of a rule with a main engraved scale and a movable jaw with an engraved vernier scale. The span of the lower jaw is used to measure length and is particularly convenient for measuring the diameter of a cylindrical object. The span of the upper jaw is used to measure distances between two surfaces (e.g. the inside diameter of a hollow cylindrical object).

The main scale is calibrated in centimeters with a millimeter least count, and the movable vernier scale has 10 divisions that cover 9 divisions on the main scale. Figure 3 shows an example of reading the vernier scale on a caliper.

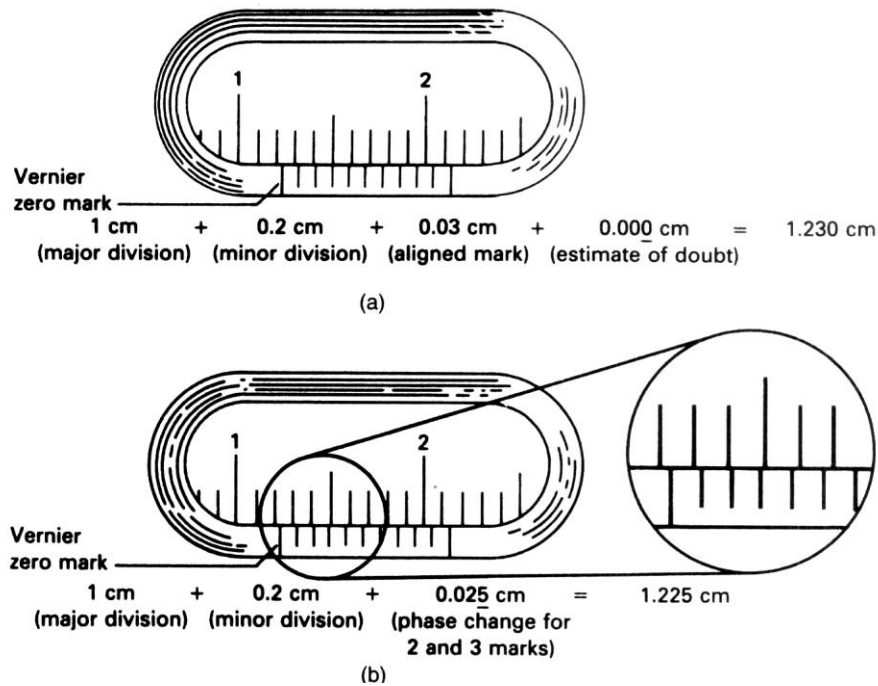


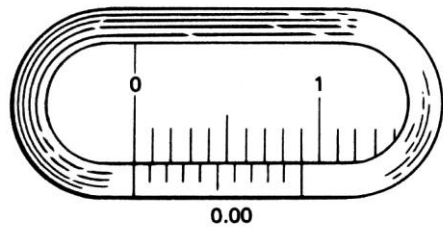
Figure 3 Vernier scale. Examples of reading the vernier scale on a caliper.

The first two significant figures are read directly from the main scale. The vernier zero mark is past the 2-mm line after the 1-cm major division mark, so we have 1.2 cm. The next significant figure is the fractional part of the smallest subdivision on the main scale. This is obtained by referring to the vernier scale markings.

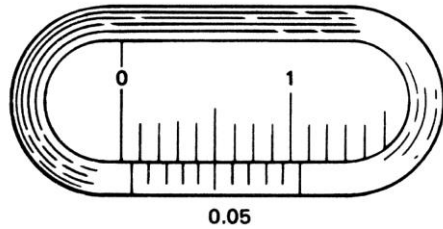
If a vernier mark coincides with a mark on the main scale, then the mark number is the fractional part of the main-scale division. In figure 3a, this is the third mark to the right of the vernier zero, so the third significant figure for a reading is 3 (0.03 cm). Finally, since the 0.03-cm reading is known exactly, a zero is added as the doubtful figure for a reading of 1.230 cm or 12.30 mm. Note how the vernier scale gives more significant figures or extends the precision.

However, a mark on the vernier scale may not always line up exactly with one on the main scale (figure 3b). In this case, there is more uncertainty in the 0.001-cm or 0.01-mm figure. In figure 3b, the second vernier mark after the zero is to the right of the closest main-scale mark and the third vernier mark is to the left of the closest main-scale mark. Hence, the marks change phase between 1.22 cm and 1.23 cm. Most vernier scales are not fine enough to make an estimate of the doubtful figure, so a suggested method is to take the middle of the digit for a reading of 1.225 cm.

Before making a measurement, the zero of the vernier caliper should be checked with the jaws completely closed. It is possible that through misuse the caliper is no longer zeroed. And thus gives erroneous readings (systematic error). If this is the case, a zero correction must be made for each reading. In figure 4 (b), the “zero” reading is +0.05 cm and this amount must be subtracted from each measurement reading. Similarly, if the “zero” reading is negative, or the vernier zero lies to the left of the main-scale zero, the measurements will be too small and the zero correction must be added to the measurement readings.



(a) Properly zeroed



(b) Positive error +0.05 cm
(subtracted from measurement reading)

Figure 4 **Zeroing and error**

Zeroing the vernier caliper with the jaws closed.

(a) zero error.

(b) positive error +0.05 cm.

- **Micrometer Caliper**

Figure 5 shows a micrometer and an example of a micrometer reading.

The micrometer provides for accurate measurements of small lengths and is particularly convenient in measuring the diameters of thin wires and the thickness of thin sheet. It consists of a movable spindle (jaw) that is advanced toward another, parallel-faced jaw (called an anvil) by rotating the thimble. The thimble rotates over an engraved sleeve (or “barrel”) mounted on a solid frame.

Most micrometers are equipped with a ratchet (ratchet handle to far right in figure 5) which allows slippage of the screw mechanism when a small and constant force is exerted on the jaw. This permits the jaw to be tightened on an object with the same amount of force each time. Care should be taken not to force the screw, so as not to damage the measured object and/or the micrometer.

The axial main scale on the sleeve is calibrated in millimeters, and the thimble scale is calibrated 0.01 mm. The movement mechanism of the micrometer is a carefully machined screw with a pitch of 0.5 mm.

The axial line on the sleeve main scale serves as a reading line. Since the pitch of the screw is 0.5 mm and there are 50 divisions on the thimble, when the thimble is turned through one of its divisions, the thimble moves $\frac{1}{50}$ of 0.5 mm or 0.01 mm ($\frac{1}{50} * 0.5 \text{ mm} = 0.01 \text{ mm}$).

One complete rotation of the thimble (50 divisions) moves it through 0.5 mm, and second rotation moves it through another 0.5 mm.

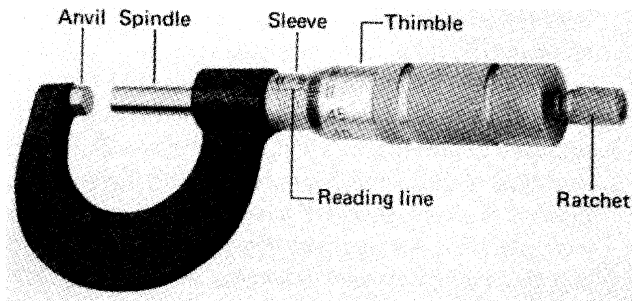
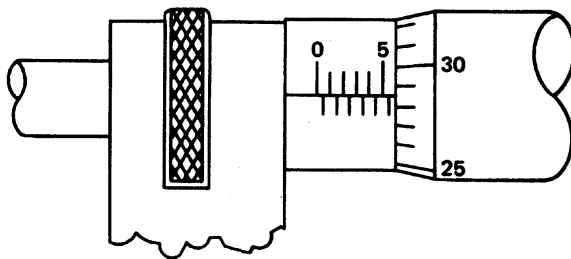


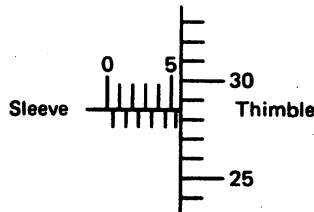
Figure 5 Micrometer

(a) This particular mike has the 1.0 mm and 0.5 mm scale divisions below the reading line.



(b) In this diagram, as on some mikes, the 1.0 mm divisions are above the reading line and the 0.5 mm divisions are below it.

The thimble in the diagram is in the second rotation of a mm movement, as indicated by its being past the 0.5 mm mark.



The reading is $5.500 + 0.285$ or 5.785 mm, where the last 5 is the estimated figure.

- **Laboratory Balances**

Laboratory balances are used to balance the weight of an unknown mass m against that a known mass m_1 , i.e. $mg = m_1g$ or $m = m_1$.

- **Density**

The density ρ of a substance is defined as the mass m per volume V , i.e. $\rho = \frac{m}{V}$. This may be determined experimentally by measuring the mass and volume of a sample of a substance and calculating the ratio $\frac{m}{V}$. The volume of a regular shaped object can be calculated from length measurements; for example:

Sphere	$V = \frac{1}{6} \pi D^3$	D, diameter
Rectangular block	$V = L_1 \cdot L_2 \cdot L_3$	L_1 , length; L_2 , width; L_3 , thickness
Cylinder	$V = \frac{1}{4} \pi D^2 L$	D, diameter; L, height
Annular Cylinder	$V = \frac{1}{4} \pi (D_1^2 - D_2^2) L$	D_1 , outer diameter; D_2 inner diameter; L, height

PROCEDURE

- Using the appropriate measuring instruments.
- Take five measurements to determine the average dimensions of each object. Notice the significant figures of the reading. Remember to make a zero correction for each reading if it is necessary.
- Calculate the volume of each object ($\bar{V} \pm \bar{dV}$). Here \bar{V} is the mean of volume and \bar{dV} is the mean deviation of volume.
- Using laboratory balance to determine the mass (m) of each object.
- Calculate the density ($\bar{\rho} \pm \bar{d\rho}$) of the material of each object. Here $\bar{\rho}$ is the mean of density and $\bar{d\rho}$ is the mean deviation of density.
- Compare the measured $\bar{\rho}$ with accepted ρ of each object and calculate the percent %.

A. Steel Ball

	1	2	3	4	5	average
D (mm)						
$v = \frac{1}{6} \pi D^3$						
$ d_{Vi} = V_i - \bar{V} $						
m (g)						
ρ (g/mm ³)						
$ d_{\rho i} = \rho_i - \bar{\rho} $						

Compare the measured $\bar{\rho}$ with accepted ρ_{Fe} ($7.8 \cdot 10^3 \text{ kg/m}^3$) and calculate the percent % error.

B. Aluminum Block

	1	2	3	4	5	average
L_1 (cm)						
L_2 (cm)						
L_3 (cm)						
$V = L_1 \bullet L_2 \bullet L_3$						
$ d_{V_i} = V_i - \bar{V} $						
m (g)						
ρ (g/cm ³)						
$ d_{\rho_i} = \rho_i - \bar{\rho} $						

Compare the measured $\bar{\rho}$ with accepted ρ_{Al} ($2.7 \cdot 10^3$ kg/m³) and calculate the percent % error.

C. Cylinder

	1	2	3	4	5	average
D (mm)						
L (cm)						
$v = \frac{1}{4} \pi D^2 L$						
$ d_{V_i} = V_i - \bar{V} $						
m (g)						
ρ (g/mm ³)						
$ d_{\rho_i} = \rho_i - \bar{\rho} $						

Compare the measured $\bar{\rho}$ with accepted $\rho_{bras.}$ ($8.9 \cdot 10^3$ kg/m³) and calculate the percent % error.

D. Alunnar Cylinder

	1	2	3	4	5	average
L (cm)						
D_1 (cm)						
D_2 (cm)						
$v = \frac{\pi L}{4} (D_1^2 - D_2^2)$						
$ d_{V_i} = V_i - \bar{V} $						
m (g)						
ρ (g/cm ³)						
$ d_{\rho_i} = \rho_i - \bar{\rho} $						

Compare the measured $\bar{\rho}$ with accepted ρ_{Al} ($2.7 \cdot 10^3$ kg/m³) and calculate the percent % error.