Experiment #1: Density Measurements

Overview. The goal of this lab is to measure the **density ($\boldsymbol{\rho}$)** of various samples: $\boldsymbol{\rho = \frac{\text{mass}}{\text{volume}}}$

You'll do this using three different methods, each with their own advantages and disadvantages. The choice of method will be determined by the sample geometry:

- **Method 1:** direct mass and length measurements on cylinder-shaped metals rods
- **Method 2:** density bottle measurements on small irregular pieces of rock
- **Method 3:** buoyancy measurements on a large irregular mechanical component

For each method, our goal is not only to determine the sample density, but also to estimate uncertainty. To this end, take five independent measurements for every directly measured quantity (such as mass, length, and diameter).

Results should be written with a mean (X), standard deviation (Y), and number of samples (n):

$$\rho = X \pm Y \ (n = ?)$$

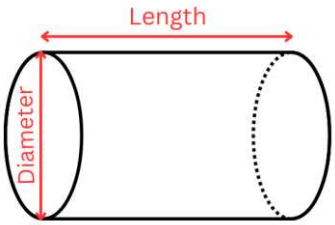
Be sure to account for significant figures when writing these results.

Method 1: Samples with a regular shape

This method relies on the direct measurement of an object's volume and mass. It is well suited for objects with a "regular" shape (like a cylinder) whose dimensions are easily measurable and related to the sample volume. In this case, we will examine metal rods.

What you will measure:

- Length (L)
- Diameter (d)
- Mass (m)



$$V = \pi L \left(\frac{d}{2}\right)^2$$

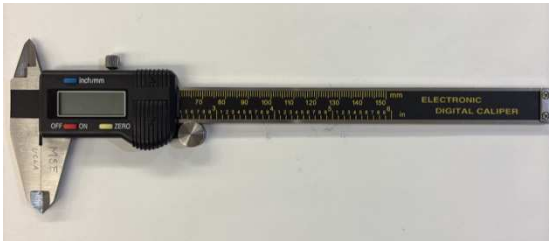
Step-by-step walkthrough:

1. Zero the instrument (micrometer or caliper, shown on next page)
   - Close the micrometer or caliper completely and tare (zero) it before any measurements are performed.
2. Measure diameter
   - Use the micrometer or caliper to measure the rod diameter.

- Do this five times at different points along the rod.
    - Near one end, near the other, in the center, *etc.*
- Record all measurements.

3. Measure length
    - Use the caliper to measure the rod length end-to-end.

Digital Caliper



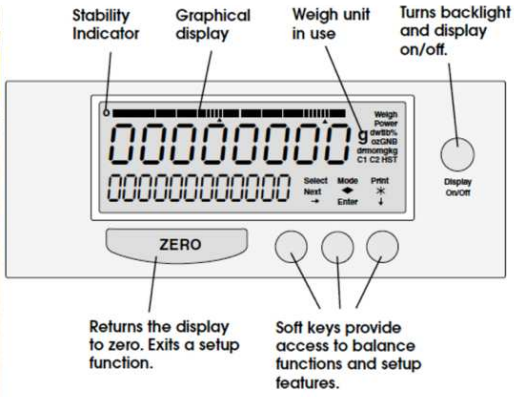
Digital Micrometer



4. Measure mass
    - Place weighing dish on the scale.
    - Press TARE/ZERO.
    - Place the rod on the dish.
    - Record the mass.
    - Repeat this five times. Each time be sure to remove the sample and re-zero the scale before placing the sample back on it.



5. Compute density
    - From the measured mass and volume, compute the density and record it. Be sure to write the mean, standard deviation, and number of samples.
    - Don't forget to account for uncertainty propagation when calculating the standard deviation!



Method 2: Small samples with an irregular shape

This method relies on the use of a density bottle, which has a **fixed volume (10 mL)**. When you insert the stopper, excess liquid leaves through the capillary, so the bottle ends up filled to the same final volume every time. You will use mass differences (of the bottle *with* and *without* the sample) to figure out the volume of stone pieces.

What you will measure: <u>5 times each</u>

- Mass of the empty bottle (m_{bottle})
- Mass of the stone (m_{sample})
- Mass of the bottle + sample + water (m_{total})

Density bottle



Step-by-step walkthrough:

1. Weigh the empty bottle ($\times 5$)
   - Make sure the bottle is completely dry.
   - Place a weighing dish on the scale.
   - Tare/zero the scale.
   - Place the dry bottle on the scale.
   - Record the mass (m_{bottle}).
   - Remove and repeat until you have five measurements.
2. Weigh the sample ($\times 5$)
   - Place a weighing dish on the scale.
   - Tare/zero the scale.
   - Place the stone on the paper.
   - Record the mass (m_{sample}).
   - Remove and repeat until you have five measurements.

Stone pieces



3. Put the sample into the bottle and fill it with water.
   - Carefully drop the sample into the empty bottle, then add water into the bottle until it is nearly full. Make sure no air bubbles are present. Tap as needed.
   - Fill until the water level is high enough that when you insert the stopper, it will overflow through the capillary.

4. Insert the stopper.
    - Insert the stopper slowly.
    - Press down gently until fully seated.
    - Water should come out of the capillary/side tube.
    - Wait about 10 seconds for dripping to stop.
5. Dry the outside completely.
    - Use a chemwipe or paper towel to dry the bottle exterior.
    - The bottle must be dry outside or the mass will be wrong!
6. Weigh the filled bottle with the sample inside ($\times$ 5)
    - Place a weighing dish on the scale.
    - Tare/zero the scale.
    - Place the filled bottle on the paper.
    - Record the total mass (m_{total}).
    - Remove and repeat until you have five measurements.
7. Calculate the density.
    - Determine the mass of the water inside the bottle (when the sample is present)
    - Convert water mass → water volume using the known water density (see table).
    - Compute the density of the sample from its mass and volume. Write this with the mean, standard deviation, and number of samples.

T (°C)	g/cm^3
18	0.998599
19	0.998408
20	0.998207
21	0.997995
22	0.997773

Water density

Method 3: Large samples with an irregular shape

This method leverages Archimedes' principle, which states that when an object is fully immersed in a fluid, it experiences an upward buoyant force equal to the weight of the fluid it displaces. As a result, the object appears to weigh less when submerged than when it is hanging in air. The difference between the measured weight in air and the measured weight in water is the buoyant force, and from that buoyant force we can calculate the object's volume. Once the volume is known, the density follows.



Large sample

What you will measure: <u>5 times each</u>

- Mass of the sample in air ($m_{\text{in air}}$)
- Mass of the sample in water ($m_{\text{in water}}$)

Step-by-step walkthrough:

Hanging Scale



1. Weigh the sample in air (× 5)
   - Set up the hanging scale apparatus (see right).
   - Make sure it reads zero before attaching anything.
   - Hang the sample from the hook. Wait for the reading to stabilize. Record the mass ($m_{\text{in air}}$).
   - Repeat this five times
2. Weigh the sample while submerged in water (× 5)
   - Raise the water container until the sample is fully submerged.
   - Make sure the sample is completely underwater, but not the hook/string, and that the sample does not touch the container walls or bottom.
   - Wait for the reading to stabilize.
   - Record the mass ($m_{\text{in water}}$).
   - Repeat this five times.



Beaker for water

3. Compute the density
   - Do this by first computing the buoyant force and the volume of the object.
   - Then use these quantities to compute the density.

The below expressions may be useful:

$$F_{\text{in air}} = F_{\text{gravity}} \qquad F_{\text{gravity}} = mg$$

$$F_{\text{in water}} = F_{\text{gravity}} - F_{\text{buoyancy}} \qquad F_{\text{buoyancy}} = V\rho_{\text{water}}g$$

