Name: ______________________ Partner's Name: ____________________

Archimedes Principle

In this experiment, you will use Archimedes' Principle to measure the density of solids.

1. Apparatus:

Beaker, balances, thread, metal and wood objects, sinker and vernier caliper.

2. Archimedes Principle:

Archimedes Principle states that:

Any object, wholly or partially immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object.

The buoyant force directed upwards, B, is then given by

$$B = \rho_f V_f g, \tag{1}$$

where ρ_f is the background fluid density, and V_f is the displaced volume of fluid. Consider the situation shown in Fig. 1, where we weigh the same object both in air, and while completely submerged in water (so that the volume of the fluid displaced is equal to the object's volume, i.e. $V = V_f$). The measured weights will be different. In the first case, the weight is the usual $W_{air} = mg$. When immersed in a fluid, however, the object weighs less because of the upwards buoyancy force, and $W_{fl} = mg - B$.

Notice also that by simply taking the difference between the two weights, you can find the value of the buoyancy force,

$$B = W_{air} - W_{fl}. \tag{2}$$

Thus by measuring an objects weight in air and in water, you can calculate B and readily determine the object's volume V from Eq. (1). Remember that for a completely submerged object, the buoyant force doesn't depend on the objects mass, or its density - it only depends on its volume.

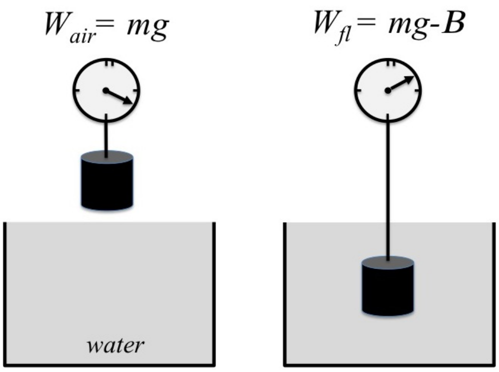

Figure 1: Weighing in object in air and in water.

3. Procedure:

You will examine two objects, a wooden block and a metallic cylinder, in this lab. The aim is to accurately determine the sample volume, V, and density, $\rho = m/V$, of each object. To start, you will simply use a scale to find the object mass m. For the object volume V however, you will use and compare the results from three different methods, shown in Fig. 2, the last two of which are attributed to Archimedes.

- The first method for determining V is to measure the sample dimensions with a ruler or caliper.
- The second method involves submerging the object in water to determine the buoyancy force B, from which V can be calculated using Eq. (1).
- The third method is to measure the the increase in water volume V when the object is immersed.

3.1. Metal Cylinder

1. **Geometric Method**
   First weigh the metal cylinder and record the mass in Table 1. Be sure that the balance is correctly zeroed before you make these measurements. Next, using the Vernier caliper, measure the radius R and height H of the cylinder, and record your data in Table 1. Finally, from your data, calculate the volume V and density $\rho = m/V$, and enter these values in Table 3, Method (1) Geometric.

2. **Archimedes Buoyancy Force Method**
   Tie a thread (we can neglect its mass) to the metal cylinder and hang it from the underside of the balance which must project over the table so that the string and cylinder hang over the edge. Fill the beaker with water and suspend the metal cylinder so that it is completely submerged. Check that no air bubbles are stuck to the cylinder. The metal cylinder must not touch the side or bottom of the beaker.
   - Measure the mass of the cylinder in water m_{wat}, calculate the weight in water $m_{wat}g$, and record these values in Table 2.
   - From the difference between the weight of the cylinder in air and in water, determine the buoyancy force B from Eq. (2), and the volume V from Eq. (1) (remember $\rho_{water} = 1000\text{kg/m}^3$),

   $B=$.

   $V=$.

   - Enter the value for V in Table 2, and Table 3, Method (2) Archimedes.

3. **Fluid Displacement Method**
   Fill a graduated cylinder about half way to the top with water. Record the volume of water. Drop the metal cylinder in the water, record the new water level, and enter the volume difference as the object's volume V in method (3) Displacement, in Table 3.

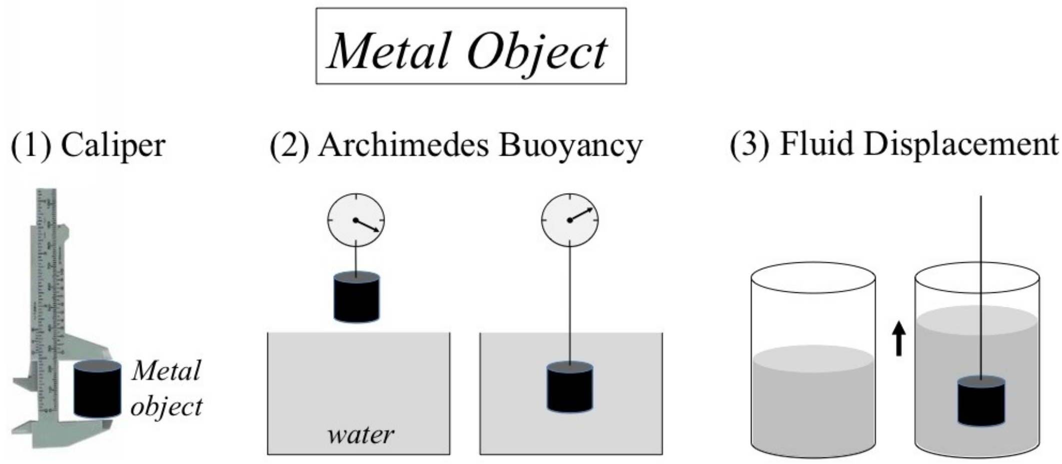

Fig.2 Three ways of measuring a metal object's volume V.

Table 1: Geometric Measurements of Metal Object

Mass	Radius	Height	Volume
m (kg)	R (m)	H (m)	$V = \pi R^2 H$ (m^3)

Table 2: Metal Volume: Archimedes Principle

Mass in Water	Weight in Air	Weight in Water	Buoyancy Force	Volume
m_{wat} (kg)	mg (N)	$m_{wat}g$ (N)	B (N)	V (m^3)

Table 3: Comparison of Metal Volumes and Densities

Method	Volume V (m^3)	Density $\rho = m/V$ (kg/m^3)
(1) Geometric		
(2) Archimedes		
(3) Displacement		
Average		

3.2. Wooden Block

1. **Geometric Method**
   First weigh the wooden block and record the mass in Table 1. Be sure that the balance is correctly zeroed before you make these measurements. Next, measure the length L, width W and height H of the wooden block, and record your data in Table 4. Finally, from your data, calculate the volume V and density $\rho = m/V$, and enter these values in Table 4 and Table 6, Method (1) Geometric.

2. **Archimedes Buoyancy Force Method**
   In order to use the Archimedes buoyancy force method to get the volume of the wooden block, you must ensure that the wooden block will be completely submerged when lowered into the water. To do this, you must first tie a small metal sinker to the bottom of the wooden block, as illustrated in Fig. 3 below. Once you've done this, tie a thread to the top of the wooden block and hang it from the underside of the balance in the same way you did for the metal cylinder.
   - Fill the beaker with water and suspend the wooden block so that the sinker is completely submerged, but the wooden block is in air. Record the scale mass m_1, and the corresponding weight $m_1 g$, in Table 5.
   - Now submerged both the block and the sinker in water. Check that no air bubbles are stuck to the wooden block. The block must not touch the side or bottom of the beaker. Record the mass m_2, and the corresponding weight $m_2 g$, in Table 5.
   - Next, from the difference between the weight of the wooden block in air and in water, determine the buoyancy force B, and from Eq. (1), the wood volume V,

   $B=$.

   $V=$.

   - Enter the value for V in Table 5, and Table 6, Method (2) Archimedes.

3. **Fluid Displacement Method**
   Fill a graduated cylinder about half way to the top with water. Drop in the metal sinker and record the volume of water. Now put the wooden block and sinker in the water, and record the new water level. Enter the volume difference as the wood volume V in Table 6, method (3) Displacement.

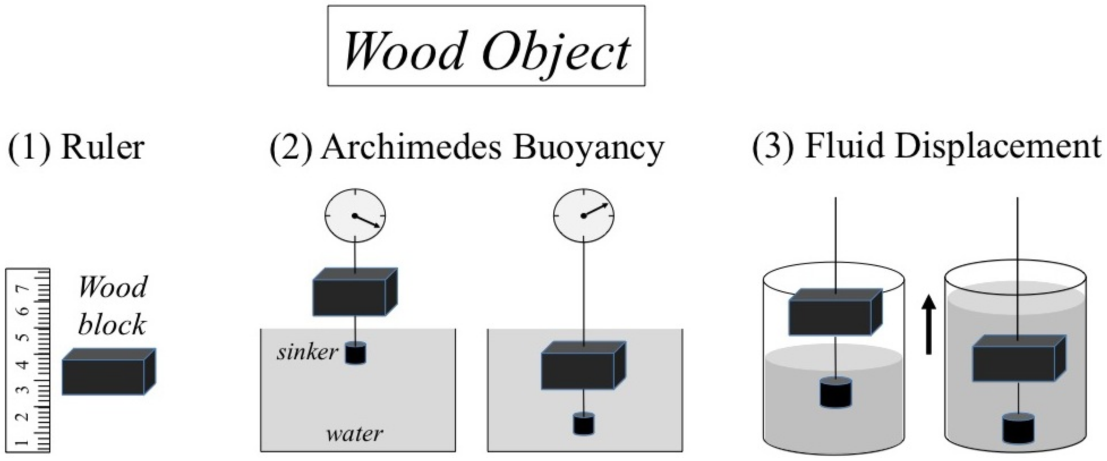

Fig.3 Three ways of measuring a wood object's volume V.

Table 4: Geometric Measurements of Wood Object

Mass	Length	Width	Height	Volume
m (kg)	L (m)	W (m)	H (m)	$V = LWH$ (m^3)

Table 5: Wood Volume: Archimedes Principle

Block in air	Block in water				
Sinker in water	*Sinker in water*	Weight$_1$	Weight$_2$	Buoyancy Force	Volume
m_1 (kg)	m_2 (kg)	$m_1 g$ (N)	$m_2 g$ (N)	B (N)	V (m^3)

Table 6: Comparison of Wood Volumes and Densities

Method	Volume V (m^3)	Density $\rho = m/V$ (kg/m^3)
(1) Geometric		
(2) Archimedes		
(3) Displacement		
Average		

4. Questions

1. Calculate the average of your three volume and density measurements for each sample in Table 6. Do the three methods yield similar values? Which method yields the largest % difference from the average? Can you explain why that might be?

2. Re-measure the masses of the wooden block and metal cylinder that you used. What are the values for m now, are they the same as you found before? If there are differences, what are the % differences from the first mass values? What would cause the mass to change, and could this be contributing to the density differences between the various values reported in Tables 2 or 3? Explain.

3. Air is a fluid, a la Archimedes, and buoys up objects immersed in it. Thus we err in not correcting for the buoyancy of air when we weigh things. Calculate the % error you made, by neglecting the buoyancy of air, in the determination of the mass of the wooden block. The density of air is $\rho_{air} = 1.29$ kg/m^3.

4. Using the listed densities of common metals, guess the metal that your cylinder is made of. Might it be a composite of more than one metal?

Material	**Density ρ (kg/m^3)**
Aluminum	2700
Zinc	7130
Iron	7870
Stainless Steel	7900
Copper	8960
Silver	10,490
Lead	11,360
Mercury	13,550
Gold	19,320

5. Imagine you travel to a faraway planet, called Oxfordia. While there you find a large rock and, being curious, you want to know all it's properties. You first measure the weight, which is 9,000N. You then submerge the rock in water, and find it's weight is only 8000N. You don't know the strength of gravity on Oxfordia, but the string holding the rock in water accidentally breaks and you obverse that the rock begins to sink with an acceleration of 2 m/s^2. What is the mass, density and volume of the rock, and what is the value for g on Oxfordia?

.

DUE NEXT WEEK...

1. The lab manual pages with all measurements done and all questions answered.

END LAB #10

- - - - - - - - - - Archimedes Principle - - - - - - - - - -