**Standards:** solid objects (two spheres and a cylinder): You will determine standard densities for **a metal sphere (sphere 1)** , **a ping pong ball (sphere 2)** and one cylinder that you will use to calculate % errors. Dimensions are measured with the vernier caliper in millimeters [mm]. Masses are measured on the electronic balance in kilograms.

Make sure the caliper is zeroed and you can read the mm scale clearly before you start. If the light fails to shine on the solar cell on the caliper it will cut off.

Dimensional measurements (with vernier caliper) : Use: 1 mm = 0.001 m

Sphere 1 diameter: $d_1$= ______ [mm] $d_1$ [m] = $d_1$[mm] / 1000 = ______ [m]

Sphere 2 diameter: $d_2$= ______ [mm] $d_2$ [m] = $d_2$[mm]/1000 = _________ [m]

Cylinder diameter: $d_{cylinder}$= ______ [mm] $d_{cylinder}$ [m]=$d_{cylinder}$[mm]/1000=_______[m]

Cylinder height: $h_{cylinder}$ = ______ [mm] $h_{cylinder}$ [m] = $h_{cylinder}$ [mm] / 1000 = ______ [m]

Volumes For a sphere (using the diameter in meters): $V_{sphere}$ [m³] = $(\pi / 6) \cdot d^3$

For a cylinder (using diameter and height in meters): $V_{cylinder}$ [m³] = $(\pi / 4) \cdot d^2 \cdot h$

Now calculate the volumes of your three objects.

Sphere 1: $V_1$ [m³] = $(\pi / 6) \cdot d_1^3$ = __________________________ = ______ [m³]

Sphere 2: $V_2$ [m³] = $(\pi / 6) \cdot d_2^3$ = __________________________ = ______ [m³]

Cylinder: $V_{cylinder}$ [m³] = $(\pi / 4) \cdot d_{cylinder}^2 \cdot h_{cylinder}$ = __________________________ = ______ [m³]

Masses (from electronic scale):Record each mass directly from the balance in kilograms [kg].

$m_1$ = ______ [kg] (Sphere 1) :$m_2$ = ______ [kg] (Sphere 2): $m_{cylinder}$ = ______ [kg] (Cylinder)

Densities (**standard values** from your measurements): Use $\rho = m / V$ in SI units.

Sphere 1: $\rho_1$ [kg/m³] = $m_1$ [kg] / $V_1$ [m³] = __________________________ = ______[kg/m³]

Sphere 2: $\rho_2$ [kg/m³] = $m_2$ [kg] / $V_2$ [m³] = __________________________ = ______ [kg/m³]

Cylinder: $\rho_{cylinder}$ [kg/m³] = $m_{cylinder}$ [kg] / $V_{cylinder}$ [m³] = __________________________ = ______ [kg/m³]

These three densities are your experimental “standard densities” for these materials. **You will use them later in the lab.**

**sphere in water:** A metal sphere is hung from a spring scale inside a graduated cylinder. Water is poured in until the sphere is completely submerged.

( ) I observed that the reading on the spring scale decreased after the water first touched the sphere.

1. Spring scale readings :
Mass reading from the spring scale before any water touches the sphere: $m_{before}$ = ______ [g]

Mass reading after the graduated cylinder has been filled so that the metal sphere is completely submerged:
$m_{after}$ = ______ [g]

(You will use $m_{before}$ as the mass of the sphere for this part.
The difference $m_{before} - m_{after}$ is related to the buoyant force.)

2. Water levels in the graduated cylinder

Record the water level (in mL) when the sphere is completely submerged in water.

Water level before removing sphere 1: $V_{before}$ = ______ [mL]

Water level after removing sphere 1: $V_{after}$ = ______ [mL]

Change in volume (this is the volume of the sphere in mL):

$\Delta V$ [mL] = $|V_{before}$ [mL] − $V_{after}$ [mL] | = ______ [mL]

Note: this is now absolute value because graduated cylinders may have 0 at the bottom or 100 at the bottom. Taking the absolute value makes sure the change in volume is always positive.

3. Convert your measurements to SI units Mass: convert grams to kilograms.

$m_{sphere}$ [kg] = $m_{before}$ [g] / 1000 = ______ [kg]

Volume: convert mL to m³: Use 1 mL = 1 cm³ and 1 cm³ = $1.0 \times 10^{-6}$ m³.

Example (do not fill in): 250 [mL] = $250 \times 1.0 \times 10^{-6}$ [m³/mL] = $2.50 \times 10^{-4}$ [m³]

Now do this for your sphere: $V_{sphere}$ [m³] = $\Delta V$ [mL] × $1.0 \times 10^{-6}$ [m³/mL] = ______ [m³]

4. Density of the sphere from this experiment: Use $\rho = m / V$ in SI units.

$\rho_{sphere\ measured}$ [kg/m³] = $m_{sphere}$ [kg] / $V_{sphere}$ [m³] = _________________________ = ______ [kg/m³]

5. Percent error compared to your standard density

From the standards section (solid objects), you already found a “standard” density for this sphere:

$\rho_{sphere\ standard}$ [kg/m³] = ______ [kg/m³]

Percent error (use the formula given):

% error = 100 × ($\rho_{sphere\ standard} - \rho_{sphere\ measured}$) / $\rho_{sphere\ standard}$

% error = 100 × (________________ − ________________) / ________________ = ______ [%]

**Cylinder in water:** A metal cylinder is hung from a spring scale inside a graduated cylinder. Water is poured in until the cylinder is completely submerged.

( ) I observed that the reading on the spring scale decreased after the water first touched the cylinder.

1. Spring scale readings :
Mass reading from the spring scale before any water touches the cylinder: $m_{before}$ = ______ [g]

Mass reading after the graduated cylinder has been filled so that the metal cylinder is completely submerged:

$m_{after}$ = ______ [g]

(You will use $m_{before}$ as the mass of the cylinder for this part.
The difference $m_{before} - m_{after}$ is related to the buoyant force.)

2. Water levels in the graduated cylinder

Record the water level (in mL) when the cylinder is completely submerged in water.

Water level before removing the cylinder: $V_{before}$ = ______ [mL]

Water level after removing the cylinder: $V_{after}$ = ______ [mL]

Change in volume (this is the volume of the cylinder in mL):

$\Delta V$ [mL] = $|V_{before}$ [mL] $- V_{after}$ [mL] $|$ = ______ [mL]

Note: this is now absolute value because graduated cylinders may have 0 at the bottom or 100 at the bottom. Taking the absolute value makes sure the change in volume is always positive.

3. Convert your measurements to SI units Mass: convert grams to kilograms.

$m_{cylinder}$ [kg] = $m_{before}$ [g] / 1000 = ______ [kg]

Volume: convert mL to $m^3$: Use 1 mL = 1 $cm^3$ and 1 $cm^3$ = $1.0 \times 10^{-6}$ $m^3$.

Example (do not fill in): 250 [mL] = $250 \times 1.0 \times 10^{-6}$ [$m^3$/mL] = $2.50 \times 10^{-4}$ [$m^3$]

Now do this for your cylinder: $V_{cylinder}$ [$m^3$] = $\Delta V$ [mL] $\times 1.0 \times 10^{-6}$ [$m^3$/mL] = ______ [$m^3$]

4. Density of the cylinder from this experiment: Use $\rho = m / V$ in SI units.

$\rho_{cylinder\ measured}$ [kg/$m^3$] = $m_{cylinder}$ [kg] / $V_{cylinder}$ [$m^3$] = __________________________ = ______ [kg/$m^3$]

5. Percent error compared to your standard density

From the standards section (solid objects), you already found a "standard" density for this cylinder:

$\rho_{cylinder\ standard}$ [kg/$m^3$] = ______ [kg/$m^3$]

Percent error (use the formula given):

% error = $100 \times (\rho_{cylinder\_standard} - \rho_{cylinder\_measured}) / \rho_{cylinder\_standard}$

% error = 100 × (________________ − ________________) / ________________ = ______ [%]

**Ping-pong ball** – density from floating depth. A ping-pong ball is placed in a cup of water. An index card is laid across about half of the top of the cup. More water is poured in (using the second cup) until the ball just touches the underside of the card. The depth rod of the vernier caliper is used to measure how far the water is below the card. You will use this "cap height" and the diameter of the ball to find the ball's density from Archimedes' principle.

1. Diameter of the ping-pong ball. You have already measured the diameter of the ping-pong ball with the vernier caliper, record that value in [m] here. $d_{Sphere2}$ = ______ [m]

Radius of the ping-pong ball: R [m] = $d_{Sphere2}$/ 2 = ______ [m]

2. Cap height (part of ball above water)

With the ball touching the underside of the index card, use the depth rod of the caliper to measure the distance from the top of the card down to the water surface. This is the height of the spherical cap that is above the water.

$h_{cap}$ = ______ [mm] $h_{cap}$ = $h_{cap}$ [mm] / 1000 = ______ [m]

3. Volumes of the ball and the cap

Total volume of the ball (sphere): $V_{total}$ [m³] = (4/3) · π · R³ = ____________________ = ______ [m³]

Volume of the spherical cap above the water (the part not submerged):

$V_{cap}$ [m³] = (π · $h_{cap}^2$ · (3R − $h_{cap}$)) / 3: $V_{cap}$ [m³] = _________________________ = ______ [m³]

Submerged volume of the ball:

$V_{submerged}$ [m³] = $V_{total}$ [m³] − $V_{cap}$ [m³] = ____________________ = ______ [m³]

4. Density of the ping-pong ball from Archimedes' principle

When the ball floats, the buoyant force equals the weight of the ball.

Buoyant force = weight of displaced water

Weight of ball = $\rho_{ball} \cdot V_{total} \cdot g$

So: $\rho_{water} \cdot V_{sub} \cdot g = \rho_{ball} \cdot V_{total} \cdot g$

The g cancels, so: $\rho_{ball} = \rho_{water} \cdot (V_{submerged} / V_{total})$

$\rho_{ball}$ [kg/m³] = 1000 [kg/m³] · (V_sub [m³] / V_total [m³])

$\rho_{ball}$ [kg/m³] = 1000 × (_______________ / _______________) = ______ [kg/m³]

Percent error (use the formula given):

% error = 100 × ($\rho_{Sphere2\ standard}$ − $\rho_{Sphere2\ measured}$) / $\rho_{Sphere2\ standard}$

% error = 100 × (_______________ − _______________) / _______________ = ______ [%]

## Helium Balloon – Worksheet Section

Mass of empty balloon (from earlier measurement): m_balloon = ______ [kg]

**1. Temperature for equations of state:** Use Kelvin in any equation of state (for example, PV = nRT).

For a temperature change, you may use either °C or K: ΔT [°C] = ΔT [K].

Fill in your measured room temperature:

T_room = ______ [°C]     T_room [K] = T_room [°C] + 273.15 = ______ [K]

**2. Atmospheric pressure from the barometer:** The barometer has three scales: Outer scale: inHg (inches of mercury), Middle scale: hPa (hectopascals, also called millibars), and the Inner scale: mmHg (millimeters of mercury).

For each scale, read the value, multiply by the correct conversion factor, and get the pressure in pascals [Pa]. Answers in pascals should be about the same.

Outer scale (inHg):     $P_{outer}$ = ______ [inHg]
1 inHg = 3386 [Pa/inHg]:     $P_{outer}$ [Pa]=$P_{outer}$ [inHg] × 3386 [Pa/inHg]  =  ______[Pa]

Middle scale (hPa):     $P_{middle}$ = ______ [hPa]

1 hPa = 100 [Pa/hPa]:     $P_{middle}$ [Pa] = $P_{middle}$ [hPa] × 100 [Pa/hPa]  =  ______[Pa]

Inner scale (mmHg):     $P_{inner}$ = ______ [mmHg]

1 mmHg=133.3[Pa/mmHg]: $P_{inner}$ [Pa]=$P_{inner}$ [mmHg]×133.3 [Pa/mmHg]=  ______ [Pa]

These three values of pressure in pascals should all be approximately the same.

Typical sea-level atmospheric pressure is about 1.013 × 10^5 [Pa]. Batesville is above sea level and the value also depends on the weather, but your three pressures in [Pa] should all be close to this order of magnitude.

Pick one value to use in later calculations:     $P_{atm}$ = ______ [Pa]

**3. Balloon pressure from the U-tube manometer**

1: Height of the water column.     $h_{low}$ =______[cm]     $h_{high}$ = ______ [cm]

2: Find the height difference and convert to meters

Δh [cm]=$h_{high}$ [cm]−$h_{low}$[cm]=______[cm]:   Δh [m]=Δh [cm]/100=______ [m]

3: Find the pressure difference between the balloon and the atmosphere.
Use ρ_water = 1000 [kg/m³], g = 9.80 [m/s²].

ΔP [Pa] = $\rho_{water}$ · g · Δh [m] = 1000 · 9.80 · Δh [m] = ______ [Pa]

Step 4: Use the atmospheric pressure from the barometer section.     $P_{atm}$  = ______ [Pa]

Step 5: Pressure inside the balloon.     $P_{balloon}$ [Pa] = $P_{atm}$ [Pa] + ΔP [Pa]  = ______ [Pa]

**4. Balloon volume (box and peanuts):**Measure only the empty part of the box where the balloon was, not the entire box. First, measure the depth of the completely empty box (stick the meter stick down the side and measure). **You are only measuring this so that you know what not to use in the calculations below.**

$d_{empty\ box}$ = ______ [cm]

Now measure the empty region where the balloon was (the "hole" in the peanuts):

L = ______ [cm]     L = ______ [m]
W = ______ [cm]     W = ______ [m]
D = ______ [cm]     D = ______ [m]

Volume of the balloon in cubic meters:

$V_{balloon}$ [$m^3$]= L [m] x W [m] x D [m] = ____________ [$m^3$]

**5. Measured lift of the balloon:** You will measure how much upward force ("lift") the balloon provides using the scale and a hanger. First measure with the balloon pulling up on the hanger, then pull down on the string attached to the balloon and measure the result without the balloon pulling.

1: Tie the balloon string a hanger and put about 10g on the hanger. Record the scale reading (hanger + any small mass + string + balloon). $m_{pulling}$ = ______ [kg]

2: Gently pull down on the balloon string so that the balloon is not pulling up on the hanger. Record the new scale reading. $m_{not\ pulling}$ = ______ [kg]

3: Find the change. Δm [kg] = $m_{not\ pulling}$ [kg] − $m_{pulling}$ [kg] = ______ [kg]

4: Compute the lift (upward force) provided by the balloon from Δm.
$Lift_{measured}$ [N] = Δm [kg] · 9.80 [$m/s^2$] = ______ [N]

**6. Number of moles of gas in the balloon** Use the ideal gas law: PV = nRT. Use $T_{room}$ from section 1, $P_{balloon}$ from section 3 and $V_{balloon}$ from section 4. Use R = 8.314 [$Pa·m^3/(mol·K)$].

$P_{balloon}$ = ______ [Pa] $V_{balloon}$ = ______ [$m^3$] $T_{room}$ = ______ [K]

Solve for n:

n [mol] = $P_{balloon}$ [Pa] · $V_{balloon}$ [$m^3$] / (R [$Pa·m^3/(mol·K)$] · $T_{room}$ [K])

n [mol] = ____________________________________________ = ______ [mol]

**7. Mass of helium and theoretical lift:** Assume the gas in the balloon is pure helium.

Molar mass of helium: $M_{He}$ = 0.00400 [kg/mol]

1: Mass of helium in the balloon. n = ______ [mol]

$m_{He}$ [kg] = n [mol] × $M_{He}$ [kg/mol] = ______ [kg]

2: Weight of the helium. $W_{He}$ [N] = $m_{He}$ [kg] × 9.80 [$m/s^2$] = ______ [N]

3: Weight of the balloon material. $m_{balloon}$ = ______ [kg]

Weight of the balloon material: $W_{balloon}$ [N] = $m_{balloon}$ [kg] × 9.80 [$m/s^2$] = ______ [N]

4: Buoyant force on the balloon (from displaced air).

Use the volume you found earlier and the density of air. Take $\rho_{air}$ = 1.20 [$kg/m^3$].

$V_{balloon}$ = ______ [$m^3$]

$F_{buoyant}$ [N] = $\rho_{air}$ [$kg/m^3$] × $V_{balloon}$ [$m^3$] × 9.80 [$m/s^2$]
$F_{buoyant}$ [N] = 1.20 [$kg/m^3$] × $V_{balloon}$ [$m^3$] × 9.80 [$m/s^2$] = ______ [N]

5: Theoretical net lift of the balloon. The theoretical lift is calculated from assuming the balloon is completely filled with helium. It is actually a test of what % helium is in the tank.

$Lift_{theory}$[N]=$F_{buoyant}$ [N]−$W_{He}$[N]−$W_{balloon}$ [N]:$Lift_{theory}$[N] = ________________________________ = ______ [N]

**8. Calculate the % deviation:**

$Lift_{theory}$ [N] = ______:$Lift_{measured}$ [N] = ______ : % deviation = 100x($Lift_{theory}$-$Lift_{measured}$)/$Lift_{theory}$=________

Estimated % helium in tank ≈ 100 × ($Lift_{measured}$ / $Lift_{theory}$) = ______ [%]