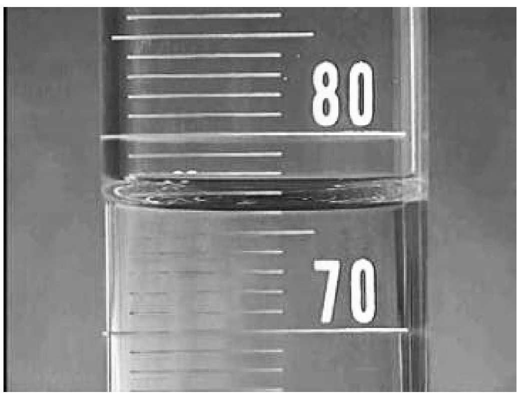
PHYS 111 NAME:
SECTION:

Laboratory 5 Pre-Lab (value: *2 marks*)

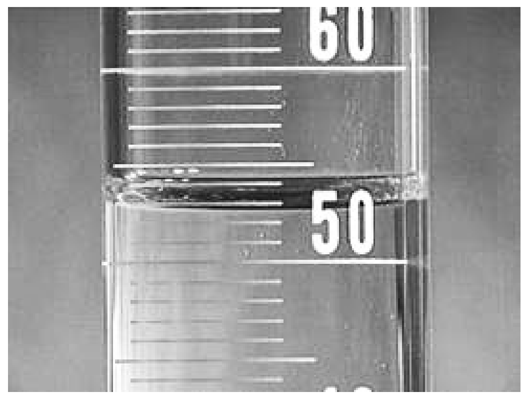
Submit to your lab instructor ***by 4pm the day BEFORE*** your lab period.

1. An object has a mass of 65.9 g and a volume of 22 mL; *calculate* its density (in g/cm^3).

2. *Determine & record the fluid volume* (in mL) measured by the graduated cylinders shown below:



(a)



(b)

3. *Compare* a measured density of 2.8 g/cm^3 for aluminum to its *expected* value of 2.70 g/cm^3.

4. How is ***apparent mass*** (m_A) defined? How does an object *behave* when m_A is *negative*?

Laboratory 5: Density and Archimedes' Principle

Experiments are to be completed on the provided laboratory sheets below; any supporting material (eg. graphs) should be attached. Make sure your name and your partners name(s) are clearly indicated on the front page of your lab. **Neatness and clarity count!** Explain your answers clearly and concisely. If an equation is to be used in a calculation, *write the equation down* and then insert numbers and solve. Report your final answer to the appropriate significant figures.

The lab write-up is due by the end of the lab. Late labs will not be accepted.

APPARATUS

Triple-beam balance, 1 kg hooked mass, 0.5 litre plastic jug, plastic 100 ml graduated cylinder, aluminum cylinder, wood cylinder, two (2) small metal paper clips, rubber bands, lab jack, container of standing room-temperature water.

OBJECTIVE

1. To find the density of a liquid, a solid which sinks, and a solid which floats.
2. To investigate buoyancy and Archimedes principle.

THEORY

Many examples of density and Archimedes' principle exist in the natural world. For example, the density of fresh water is less than that of salt water; as a result, fresh water tends to remain as a top layer near river estuaries until it is mixed in by tidal currents and wave motion. Many species of fish have a bladder filled with gas with which they can regulate their buoyancy and thus their depth in the water.

In this experiment, the density of a liquid is found from its volume and mass. The densities of solids are calculated from their measured masses and volumes. The mass of a solid is measured in air and in water. The difference between the real mass measured in air and the apparent mass measured in water is found to be equal to the mass of the water that the solid displaces.

Archimedes' principle

If an object is immersed in a *fluid* (a liquid or a gas), its apparent weight will be less than its real weight by an amount equal to the weight of the fluid it displaces. This is commonly referred to as Archimedes principle or the principle of buoyancy and is given by

$$W_A = F_g - W_F \tag{1}$$

where W_A is the apparent weight of the object in the fluid, F_g is the real weight of the object in air, and W_F is the weight of the displaced fluid.

The balances used in the lab are calibrated in mass units. However, they actually respond to weight, the force of gravity acting downward on the object placed on the balance. Since mass is linearly related to weight by $F = mg$, a balance can therefore be calibrated to read in grams.

Archimedes principle properly applies to the weight of an object. However, in order to avoid the tedious conversion of every measurement from mass to weight units *we will use the real mass and the apparent mass of an object* (as measured by the balance), even though the true mass of an object does not change - only its weight does!

With this in mind, Archimedes principle may be re-written as

$$m_A = m_R - m_F \tag{2}$$

where the subscripts are as before. This equation states that the apparent mass of an object immersed in a fluid is less than its real mass by an amount equal to the mass of the displaced fluid.

For an object to *float* in a fluid *the buoyant force must equal or exceed the force of gravity* on that object and so Equation 1 & 2 require that a floating object's apparent weight (or mass) must be *less than or equal to zero.*

Density

The SI units of mass and volume are, respectively, the kilogram and the cubic metre. However, for the measurement of small quantities, the gram and the cubic centimetre are convenient because they avoid (unnecessary) writing of powers of ten. For liquid measurements, the litre (L) and the millilitre (mL) are commonly used. Since the litre is a 10-cm cube or 1000 cm^3, one cubic centimetre and one millilitre are identical: 1 cm^3 = 1 mL.

The density of an object is found by dividing its mass m by its volume V,

$$\rho = \frac{m}{V} \tag{3}$$

Typical units are g/cm^3 or kg/m^3.

When an object is immersed in a fluid the volume of the displaced fluid is the same as the volume of the object which displaced it. An object which is less dense than a fluid will float in that fluid, sinking only to the point where the mass of the displaced fluid equals the real mass of the object.

Measurement of volume - the graduated cylinder

The graduated cylinder (see Figure 1) is commonly used for the measurement of liquid volumes. The markings on the cylinder show the volume in millilitres. Notice that the liquid surface is not a straight line but curves upward where it meets the sides of the cylinder. The liquid level is always read at the bottom of this *meniscus*. Because the bottom of the curved meniscus lies some distance behind the graduations on the cylinder, it is essential that the reading be taken while looking straight on, that is, perpendicular to the cylinder. Given the curved nature of the meniscus and the very real possibility of parallax, the reading uncertainty should be increased and the cylinder read only to the nearest division of the graduated cylinder.

Figure 1: Reading a graduated cylinder

For the graduated cylinder with 1 mL gradations shown above the volume would be read as 36 mL.

Comparing Values

Please refer to Lab 1 regarding the usage of ***percent difference*** & ***percent deviation***.

NAME:
DATE: PARTNER:

Laboratory 5: Density and Archimedes' Principle

Part A: Density of water

1. **Carefully zero the triple beam balance**.

2. [***1 mark***] Place the *empty* graduated cylinder on the balance and **record its mass** (in g):

$m_{empty\ gc} =$ ______________.

3. [***1 mark***] *Add water* to the cylinder to any point *BELOW the top of the graduations* and **record its mass & volume** (in g & mL): $m_{water+gc} =$ ______________ $V_{water} =$ ______________.

4. [***1 mark***] **Calculate the *mass of water*** (in grams) in the cylinder. *Show ALL work.*

5. [***1 mark***] **Calculate the *density of water*** (in g/cm^3). *Show ALL work/watch sig figs.*

6. [***2 marks***] **Compare** to *expected value* $\rho_{water} = 1.00$ g/cm^3 using *percent deviation.* **Comment.**

Part B: Density of an object which sinks in a liquid

Place the balance on the edge of the bench divider so that the scale pan hangs over the edge. **Place the 1.000 kg mass on the base of the balance to stabilize it**; ensure it does not interfere with balance operation. Hang a straightened paper clip from the lowest thin horizontal bar on the underside of the balance, **DIRECTLY beneath the pan**. **Remove the hook from the wood cylinder & hang it from this paper clip**. Attach a second paper clip to the *counterpoise hanger* (the small metal protrusion(s) on the *non-pan* end of the triple beam) and **re-zero the balance**.

**** Use ρ_{water} =1.00 g/cm^3 for any calculations requiring the density of water. ****

Density of aluminum

1. [***1 mark***] Suspend the aluminum cylinder from the paper clip beneath the balance.

Record the (real) mass (in g) **of the aluminum cylinder** in air: $m_R^{AL} =$ ____________.

2. [***1 mark***] Fill the graduated cylinder (NOT jug) *about* half-full with water & **record the initial volume** (in mL) below. Gently slide the aluminum cylinder (WITHOUT hook) into the graduated cylinder. Minimize trapped air bubbles by tapping on the cylinder. **Record the final volume** (in mL) below and **calculate the volume of the aluminum cylinder** in the space provided to the right. **Convert** the volume to from mL to cm^3.

$V_{initial} =$ ____________

$V_{final} =$____________

3. [***3 marks***] **Calculate the density of aluminum** using its (real) mass and volume. **Compare with its *expected* value** $\rho_{AL} = 2.70$ g/cm^3 using *percent deviation.* **Comment.** *Show ALL work.*

Buoyancy and the mass of the displaced fluid

1. Suspend the aluminum cylinder from the paper clip beneath the balance.

2. [***1 mark***] Fill the plastic jug *roughly* $^3/_4$ full & place it on the lab jack. Raise the jack until the aluminum cylinder (*excluding* the hook) is FULLY submerged but NOT touching the bottom.

Record the apparent mass (in g) **of the aluminum cylinder** in water: $m_A^{AL} =$ __________.

3. [***1 mark***] How much mass did the aluminum seem to "lose" in water? *Show ALL work.*

4. [***3 marks***] Calculate the mass of water displaced by the aluminum cylinder using the accepted density of water & V_{AL}. **Compare** the *mass of the displaced water* to the *mass "lost" by the aluminum cylinder* using *percent difference.* **Comment. Why are the masses so similar**?

5. [***1 mark***] Remove the aluminum cylinder **but leave a hook on the paperclip beneath the balance**. Place a *roughly* $^3/_4$ full plastic jug of water on the balance and **record the (initial) mass** (in g). Then, holding the aluminum cylinder by its hook, submerge it fully (*excluding* the hook) in the jug of water; hold it STEADY and **record the new (final) mass** (in g):

$m_{initial} =$ __________ $m_{final} =$__________.

6. [***3 marks***] **Calculate the change in mass**. **Is this mass value 'familiar'**, *i.e. similar to another recent result? **Why** does the mass NOT simply increase by the apparent mass of aluminum in water,* m_A^{AL}*? **What** is causing the measured increase in mass?*

[*Hint: consider* $F_{buoyant}$ *acting on the aluminum cylinder and apply Newton's Third Law.*]

Part C: Density of an object which floats in a liquid

Density of wood

1. [***1 mark***] Suspend the wood cylinder from the paper clip beneath the balance.

Record the real mass (in g) **of the wood cylinder** in air: $m_R^{wood} =$ ______________.

2. [***1 mark***] **Calculate the volume of the wood cylinder** (in mL) using the same process used previously for the aluminum; push the wood cylinder fully underwater. *Show ALL work.*

3. [***3 marks***] **Calculate the density of the wood** using its real mass & volume. **Compare with *expected* value** $\rho_{maple} = 0.7$ g/cm^3 using *percent deviation.* **Comment.** *Show ALL work.*

Buoyant effect of wood

1. [***1 mark***] Connect the wood and aluminum cylinders together using the rubber band and **determine their combined apparent mass** by suspending them **fully submerged in a jug of water** beneath the balance, *i.e. as previously for the apparent mass of the aluminum cylinder.*

$m_A^{AL+wood} =$ ____________________ (consider the mass of the rubber band to be negligible).

2. [***2 marks***] **Calculate the apparent mass of the wood cylinder** m_A^{wood} from the *difference between the apparent mass of the combination* (above) *& the apparent mass of the aluminum cylinder on its own. Show ALL work.* **What is *'unusual'* about** m_A^{wood}**? Why does this occur?**

3. Discard the water and tidy the apparatus. **Remove all paperclips from the balance**.

Optional Bonus Question

[*2 marks*] **This question must be completed during the lab for credit and without ANY help from ANY instructor.** Calculate the MINIMUM volume of wood required to float the aluminum cylinder just below the surface of the water. **Use the accepted densities for water, aluminum and wood**. **You must fully & clearly** explain your thinking/steps/work!