

Lab 11: Density and Buoyancy

Experiment for Physics 211 Lab at CSUF

What You Need To Know:

Density

A concept that you will be using frequently in today's lab is called density. Density is a measurement of an object's mass per unit volume of space that it occupies. The equation follows ...

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

ρ is the density of an object (in kilograms per meter cubed, kg/m^3) *Equation 1 – Density*
 m is the mass of the object (in kilograms, kg)
 V is the volume of space that the object occupies (in meters cubed, m^3)

In physics, as opposed to chemistry, we use units of kg/m^3 , not units of g/cm^3 . For example in chemistry the density of water is usually stated as $1 g/cm^3$. In physics, however, the density of water is stated as $1000 kg/m^3$. You will be using this value frequently during today's lab.

Float or Sink

When you place an object in a fluid it will do one of two things. It will either float or it will sink. Perhaps when you were in high school you learned that the typical way in which you can tell what the object will do is by knowing its density and how it compares to the fluid it is in. If the density of the object is *less* than the density of the fluid it is in, then it will *float*. If the density of the object is *more* than the density of the fluid it is in, then it will *sink*. This is all well and good but it doesn't really get to the heart of the matter. This lab will hopefully give you a better feel for why objects float or sink.

Archimedes Principle

Any object that is either partially or completely submerged in a fluid will always feel a *buoyant force* acting on it. A buoyant force always acts in a direction opposite to that of gravity. It can be calculated by using *Archimedes Principle* which states that an object will be buoyed upwards by a force that is equal to the weight of the fluid that the object displaces. We also know that $W = mg$ so we can alter the equation as below ...

$$F_B = W_{dis}$$

$$F_B = m_{dis}g$$

F_B is the buoyant force (in Newtons, N)
 W_{dis} is the weight of the displaced fluid (in Newtons, N)
 M_{dis} is the mass of the displaced fluid (in kilograms, kg)
 g is the gravitational acceleration (9.8 m/s^2)

Equation 2 –
Buoyant
Force

At first, people tend to find the idea of “displaced fluid” a little hard to grasp. Let’s say that you have a cube that you want to completely embed in the ground. Obviously, if you just set the object on the ground it would rest on its surface. In order for the cube to be “in” the ground you would first have to dig a cube sized hole. In other words, you are *displacing* a certain amount of dirt so that the cube will fit.

This is the same idea as *displaced fluid*, except that when you put an object in a fluid you don’t have to dig a hole, the fluid will move aside so the object will fit, but we are still displacing fluid.

It’s All About Volume

Now we are going to take the buoyant force equation and alter it a bit to get to the heart of the matter. First, we are going to take the density equation, Equation 1, and solve for mass. Next, taking that equation, we are going to plug it into the buoyant force equation, Equation 2. The m_{dis} is for the mass of the displaced *fluid* so when we plug in for the density it has to be for the *fluid*, ρ_{fl} . Also, since it’s the *displaced* fluid, the volume must be the *displaced* volume, V_{dis} .

$$m = \rho V$$

$$F_B = \rho_{fl} V_{dis} g$$

F_B is the buoyant force (in Newtons, N)
 ρ_{dis} is the density of the displaced fluid (kg/m^3)
 V_{dis} is the volume of the fluid displaced (m^3)
 g is the gravitational acceleration (9.8 m/s^2)

Equation 3 –
Buoyant
Force from
density

When you place an object in a fluid there is only one thing that you can change in the equation ($F_B = \rho_{fl} V_{dis} g$) and that’s V_{dis} . You can’t change the density since that would mean you’d have to have a completely different fluid. Also, you can’t change the gravitational acceleration, g , since that would mean you’d have to go to a different planet. So, when talking about buoyant force the most important idea to consider is how much volume you are displacing.

For example, more than likely you’ve been in a pool or the ocean and you’ve tried to push a beach ball under water. You probably never noticed at the time, but as you force the ball down into the water you have to push harder and harder. That’s because, as you are submerging the ball, you are constantly increasing the amount of water that you are displacing and therefore increasing the buoyant force acting upward on the ball. **See Figure 1.**

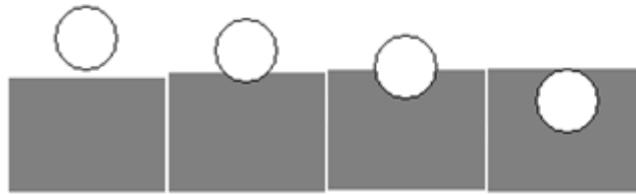


Figure 1 – Submerging a ball

Another example would be a ship on the ocean. Ocean liners are huge and weigh thousands of tons, so they need to displace huge amounts of water to stay afloat. If you could see a side view of an ocean liner above and below the waterline it would NOT look like **Figure 3a**. It would look more like **Figure 3b**.



Figure 2 – Side view of ocean tanker, left inaccurate, right accurate

What You Need To Do:

Part 1 - The Floating Case

The best way to approach a buoyancy problem is by first drawing a Free-Body Diagram and then applying Newton's 2nd Law ($\Sigma F = ma$). Let's look at a basic floating case; a block of wood floating in a container of water.

- A) Go to the back of the lab and fill the large glass beaker with about 800 mL of water. (There's also a fountain in the hall that you can use.) Take the balsa wood block (the lighter one) and slowly lower it into the water. As you lower it, have it enter the water at an angle so that bubbles will not get trapped under the block. The balsa should now be free floating.
- B) Observe the block in the beaker directly from the side. It should look similar (but not exactly) to **Figure 3**. (There is also some refraction of light taking place but ignore that.) Make a sketch of what you see in your lab report. Remove the balsa from the water and dry it with the towel.

Part 1 – Sketch 1

NOTE: Please do not let the blocks just sit in the water. Draw your sketch and remove and dry the block promptly.

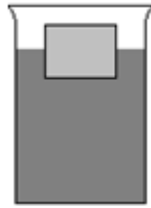


Figure 3 – Side view of floating block.

- C) In the sketch diagram you made, draw the forces that are acting on the block (i.e. a Free-Body Diagram).
- D) Next to your sketch diagram, apply Newton's 2nd Law and then solve algebraically for the buoyant force. You should conclude that $F_B = W$. If this is not your conclusion then go back and check your work. If you still do not get this result then ask your instructor for help.

This is the result that you should always get for the floating case. *The buoyant force for a floating object will always equal the weight of the object.* $F_B = W$ is our buoyant force equation for the floating case.

Question 1:

If you place a block of wood that is the same size as the balsa block but is heavier, then what will happen to the buoyant force acting on it? Explain why.

Question 2:

Referring to **Question 1**, if the buoyant force must increase to compensate for the heavier block of wood then what else must change? (If you don't know the answer then reread the introduction of this lab.)

- E) Make a table like Table 1. Use the digital scales to measure the mass (in kilograms) of the balsa block, the bubinga block (a West African wood), and the aluminum block with the hook in it. Put

Table 1 – Part 1 Data

Object	Mass (kg)	Weight	Buoyant Force	$V_{\text{dis}} (\text{cm}^3)$	$V_{\text{ob}} (\text{cm}^3)$

this data in your table. Also, calculate the weight of each object and place the values in the table. You will fill in the rest of the table later.

- F) Now take the bubinga block and slowly lower it into the water. Make sure there are no bubbles under the block. Make a side view sketch. Remove and dry the block.

Part 1 – Sketch 2

Checkpoint 1:

In examining your two sketches and your data in the table, does what you see agree with your answer from **Question 2**? Explain how.

- G) Pick up the aluminum block with the looped string. Slowly lower the aluminum block into the water. Make a side view sketch. Remove and dry.

Part 1 – Sketch 3

- H) Go back to your table and based on what you have learned *so far*, try to calculate the buoyant force for each block. Explain why you can or can't for each block. Put the values you can calculate in the table.
- I) Using information you've learned in this lab (on page 2), calculate the displaced volume for the wood blocks. Multiply your answer by 1×10^6 to convert to cm^3 .
- J) Using the vernier caliper on your table top, measure the three dimensions for each block in centimeters. Calculate the volume of each object and place it in the table. NOTE: Ignore the volume of the hook.
- K) Even though you should have left blank the buoyant force column for the aluminum block, go ahead and calculate it assuming $F_B = W$. (It's wrong, but use it anyway.) Place this value in the table. This value is what buoyant force the block would *need* in order to float. Also calculate the volume displaced for the aluminum block.

Question 3:

Why can't the aluminum block float? (You must explain this in terms of volume, NOT density.) (HINT: The answer is in the table you made.)

In comparing the two different volumes for each block you can see that the wood blocks float because their displaced volumes are *smaller* than their actual volumes. This allows them to float. For the aluminum block, the displaced volume is *larger* than the block's actual volume. *It can't displace enough water to allow itself to float.*

- L) Take the balsa block and lower it into the water until it floats. Take the flat piece of metal and place it on top of the block. Do this slowly and try to center the metal on top of the block so it doesn't tip or list. Describe what happens and why.

Checkpoint 2:

Let's say you have a row boat. One at a time people get on (and you have an unlimited supply of people). What eventually happens to the boat? Explain why in detail.

Part 2 - The Sinking Case

As before, you want to use a Free-Body Diagram and a Summation of Forces for this part. However, your block will not rest on the bottom of the beaker. Instead, it will hang suspended from a force probe. See **Figure 6a**. There are three forces acting on the block. One is the block's actual weight, another is the buoyant force, and the third is the force due to the probe. See **Figure 6b**.

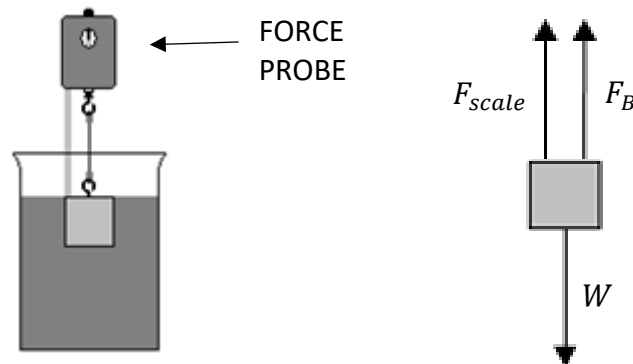


Figure 4 – Free Body Diagram (right) for suspended block (left)

The reading from the force probe will be considered to be the “apparent weight” when the block is in a fluid (as opposed to its actual weight when it is suspended in the air). **Equation 4** is a force summation on the block. After which, we solve for the buoyant force. In the last line we change W to W_{air} , which is the object's actual weight or as we say its “weight when in the air” (NOT the weight of the air). The force due to the force probe is changed to W_f (weight in the fluid) since this is what the force probe is reading. The highlighted equation is our buoyant force equation for the sinking case.

$$\sum F = ma$$

$$F_{scale} + F_B - W = 0$$

$$F_B = W - F_{scale}$$

$$F_B = W_{air} - W_{fl}$$

Equation 4 – Buoyant Force as function of Weights

You are going to be using this idea (and a couple others) to find the density of the aluminum block using three different methods.

Make a table in your lab report like the one in **Table 2**. Place in this table your density values after you calculate them for each different method.

Table 2 – Density Values

Method	Density
1	
2	
3	
Aver.:	
% diff.:	

Method 1

This first method is the easiest since you have already taken the data for it. You know the mass of the aluminum block and you know the volume of the block (turn this value back into m^3).

- A) Go back to table 1 and use those values and the density equation to calculate the density of the aluminum block.
- B) Put your value in the table, making sure your units are kilograms and meters.

Method 2

You will be using the ideas discussed above for the sinking case. Namely the end of Equation 4 ... $F_B = W_{air} - W_{fl}$. You'll need to use the force probe, the beaker of water, and the aluminum block. For each section below, make sure you show your work.

- A) Open the file FORCE PROBE.
- B) With only the looped string hanging from the force probe, push ZERO on the computer to zero out the probe.
- C) Again, W_{air} is just the weight of the block while it's in the air. You already know that value from Part 1 of the lab. Write down this value in this section of your report.
- D) To find W_{fl} first hang the aluminum block from the force probe and lower it into the water so that the top of the block is just below the water line. See Figure 4. The force probe reading will be the "apparent weight" of the block when it submerged.
- E) Use Equation 4 to find the buoyant force.
- F) Now use the buoyant force equation from Equation 3 to calculate the displaced volume of water from the block. What is the physical relationship between the volume of the displaced water and the volume of the block?
- G) Use the density equation (Equation 1), the mass of the block you measured earlier, and the volume of the block you got in F) to find the density of the block. Put this value in table 2.

Method 3

For the last method you will be using the metal cup with the spout and the small metal bucket with the hanger (this is the catch bucket).

- A) Find the mass of the catch bucket using a digital scale in the lab.
- B) Place the catch bucket under the spout of the other metal cup. Pour water from the beaker into the spouted cup until water comes out of the spout. Let the water run out until it stops.

NOTE: Do not bump the spouted cup. You want the water in the spouted cup to be just ready to come out of the spout.

- C) Empty the water from the catch bucket back into the *glass beaker*. Dry the catch bucket using the towel on your table. Place the catch bucket back under the spout.
- D) Attach the string to the aluminum block and lower it into the spouted cup. Water will come out of the spout into the catch bucket. Lower the block until it hits the bottom of the cup. The water that comes out of the spout represents the *displaced water* from the block.
- E) With the water still in the catch bucket, measure the mass of the water and bucket together using a digital scale. Record the mass. Subtract from this value the mass of just the cup that you measured earlier. You now have the mass of the displaced water.
- F) Use the density equation to find the volume of the displaced water. Like before, this is the same as the volume of the block since it is totally submerged.

- G) Calculate the density of the block and record the value in your table.
- H) Calculate the average density. Calculate a percent difference between this value and the actual density of aluminum which is 2700 kg/m^3 . If you get a percent difference more than 15% you must find your error.

Metal	Density
Gold	$19,300 \text{ kg/m}^3$
Lead	$11,300 \text{ kg/m}^3$
Brass	$8,400 \text{ kg/m}^3$
Cast Iron	$6,800 \text{ kg/m}^3$
Titanium	$4,500 \text{ kg/m}^3$

Figure 5 – Known Densities of Metals

Unknown Block

Now measure the “unknown” metal block and use what you’ve learned to find out what it is:

Question 4:

- a) Use either Method 2 or Method 3 to find the density of the “unknown” metal box.
- b) Use Figure 5 to determine what type of metal its made out of.

Clean Up

Empty the water out of all the containers. Dry all containers. Dry the blocks. If there is any water on your table then wipe it up. Leave the towel flat on the table so it will have time to dry before the next lab. Thanks!

Conclusion

Follow the lab report guide to write a conclusion on this lab.

Submit any excel or graphical analysis data your instructor requests along with your report.

Conclusion

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