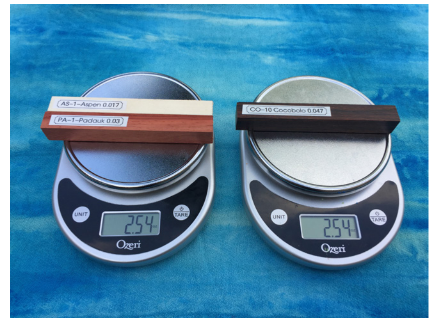
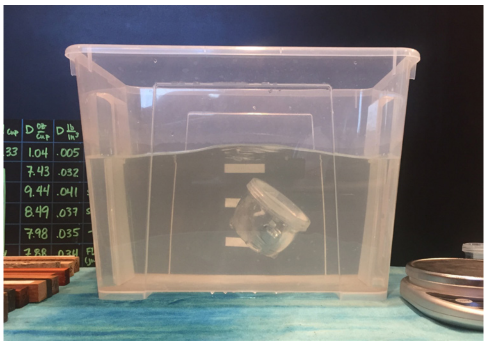
BUOYANCY EXPERIMENT – OVERVIEW



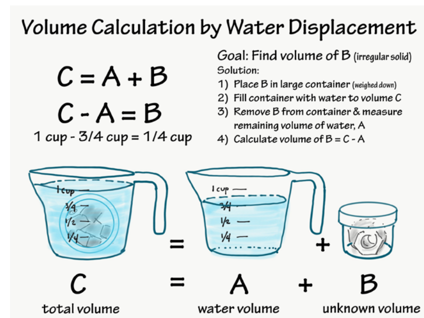
Understanding DENSITY & exploring what floats or sinks

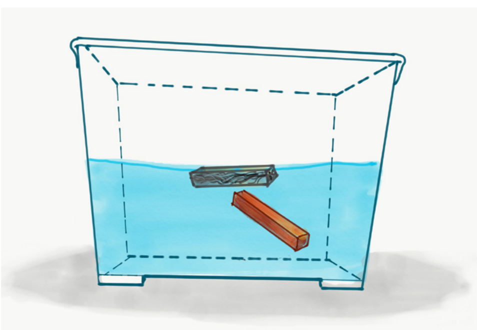
- Density = weight per unit volume
- Does not depend on SIZE
- Great way to compare how "heavy" something is compared to a fluid like water



Finding Neutral Buoyancy

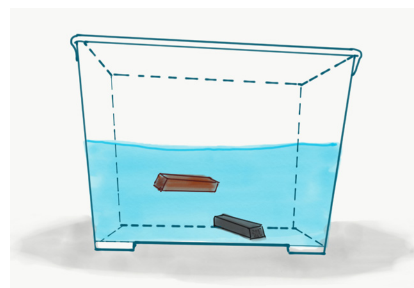
- 8 oz Lock-up container
- Add washers until it sinks
- Try for hover condition
- Weigh container, calculate density given volume
- Compare density with density of water. Is it close?

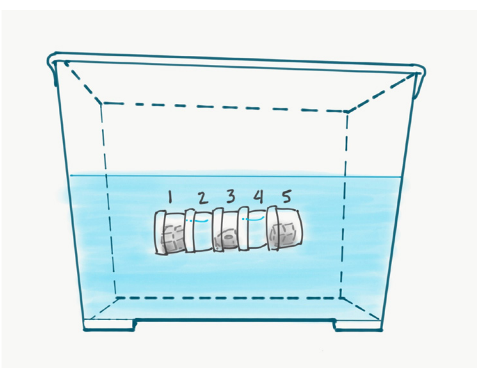




Testing Hypothesis - object floats if density is < density of water

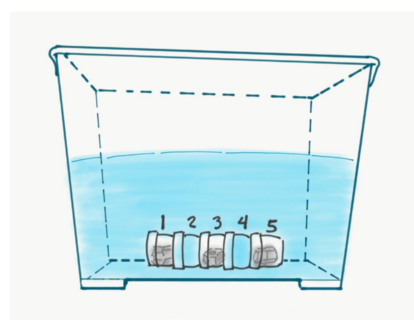
- 6 wood samples per team
- Densities marked on samples
- Predict behavior & test
- Paired races - flotation tests, sinking tests
- Does density predict behavior?

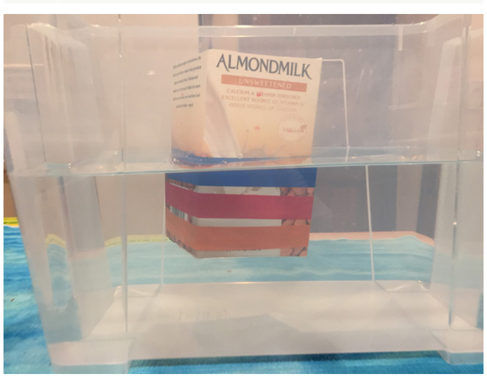




Submarine Simulation

- Use 1.5 oz Lock-up cups, with nuts in chambers 1,3,5
- Chambers 2, 4 used for ballast
- Fill 2,4 with air - sub floats
- Fill 2,4 with water - sub sinks
- Find amount of water needed in 2,4 for neutral buoyancy



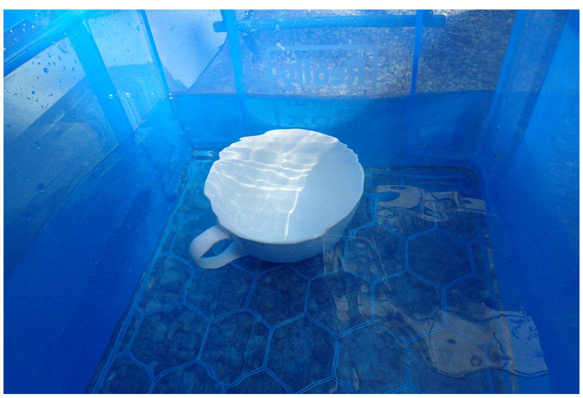


Size a Boat, use of Safety Factors (Margin)

- Water pushes up with a force equal to its density times the volume of water displaced ... we can use this to size a boat
- Using a milk carton with 1″ waterline measurements, add weight until the water reaches the 3″ mark
- Compare results with table of calculations
- Add safety margin (for waves, etc.)
- Given a desired payload weight, calculate how many cubic inches of water you'd need to displace

Plastic spoon floats while metal sinks

Ceramic mug floats when empty ...



but sinks when it takes on too much water

Neutral buoyancy ... hovering mid-water

Why do some things float while others don't?

- How do **ships made of steel** carry people and cargo across the oceans?
- How do submarines **submerge** ↓ and then **surface** ↑ in the ocean?
- Why can I **float** more easily on my **back**, not positioned **vertically** in deep water?

Key Terms:

Buoyancy

- The ability to **float in water** *or* **air** or some other **Fluid**
- An upward **force** ↑ that opposes the **weight** ↓ of an immersed object

Fluid

- A substance that has **no fixed shape** and yields easily to **external pressure**; a gas or (especially) a **liquid**

+ Positive Buoyancy = FLOAT

– Negative Buoyancy = SINK

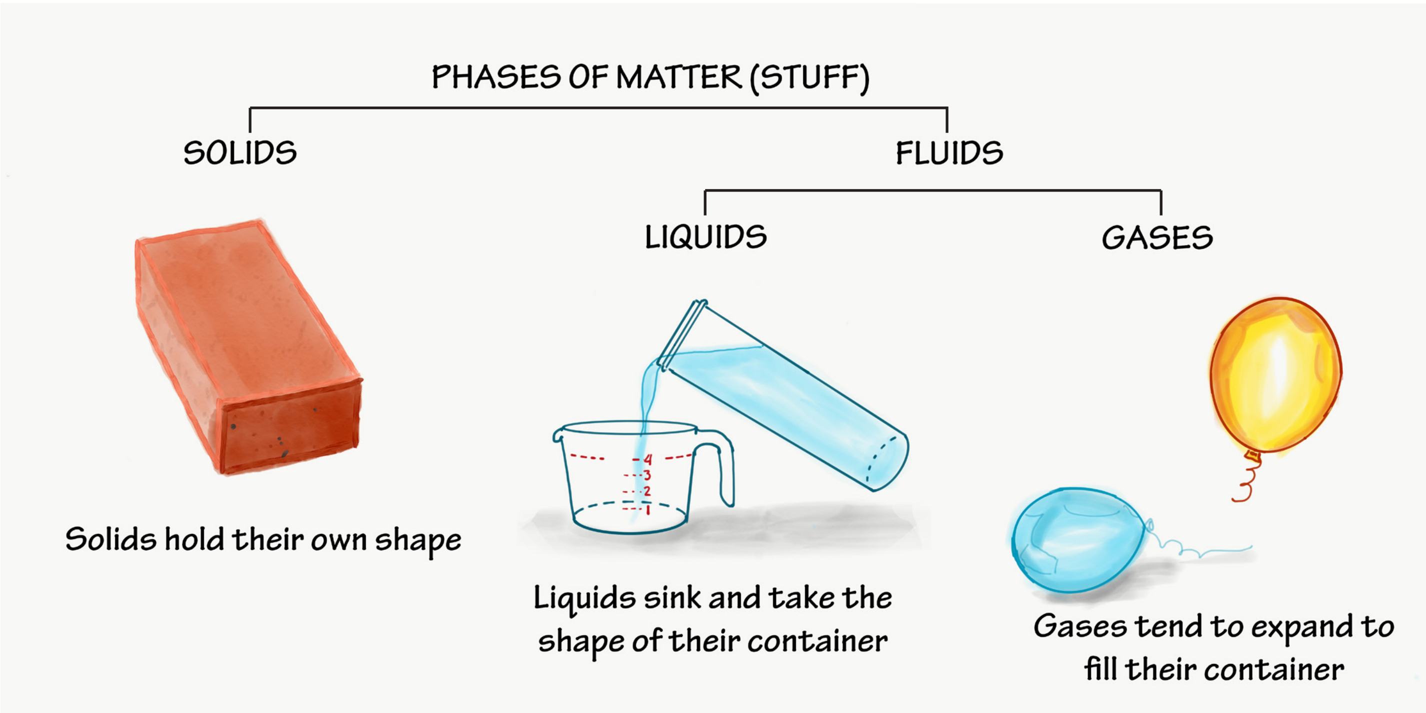
~ Neutral Buoyancy = ???

When neutral buoyancy is achieved, the object is able to "**hover**" in mid-water with minimal effort, neither sinking to the bottom or rising to the surface.

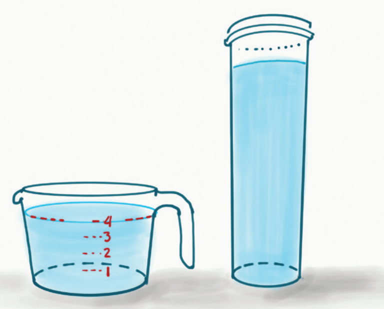
If we can figure out the criteria for **Neutral Buoyancy**, then we can predict whether an object will sink or float. We could **design a boat** to carry a desired load. We can figure out how to increase our buoyancy while swimming or treading water.

BUOYANCY EXPERIMENT

PHASES OF MATTER

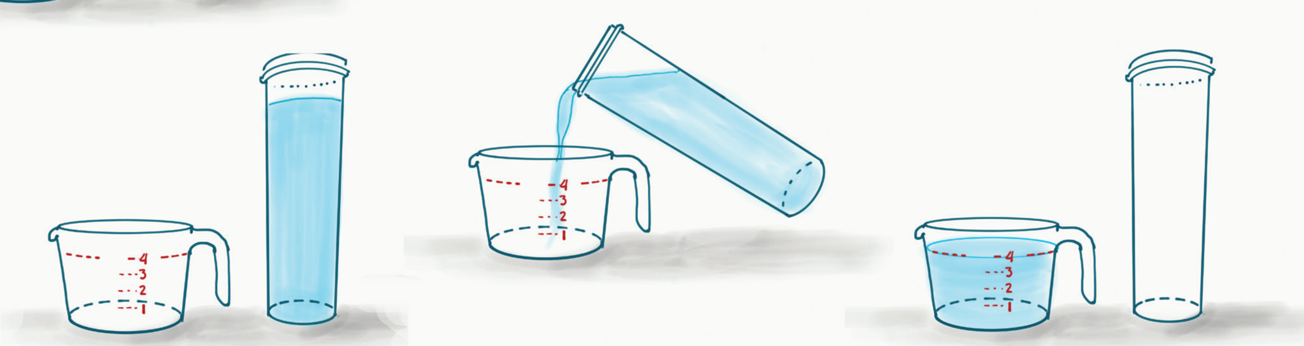


MATH IS MAGICAL! WHICH CONTAINER HOLDS MORE?

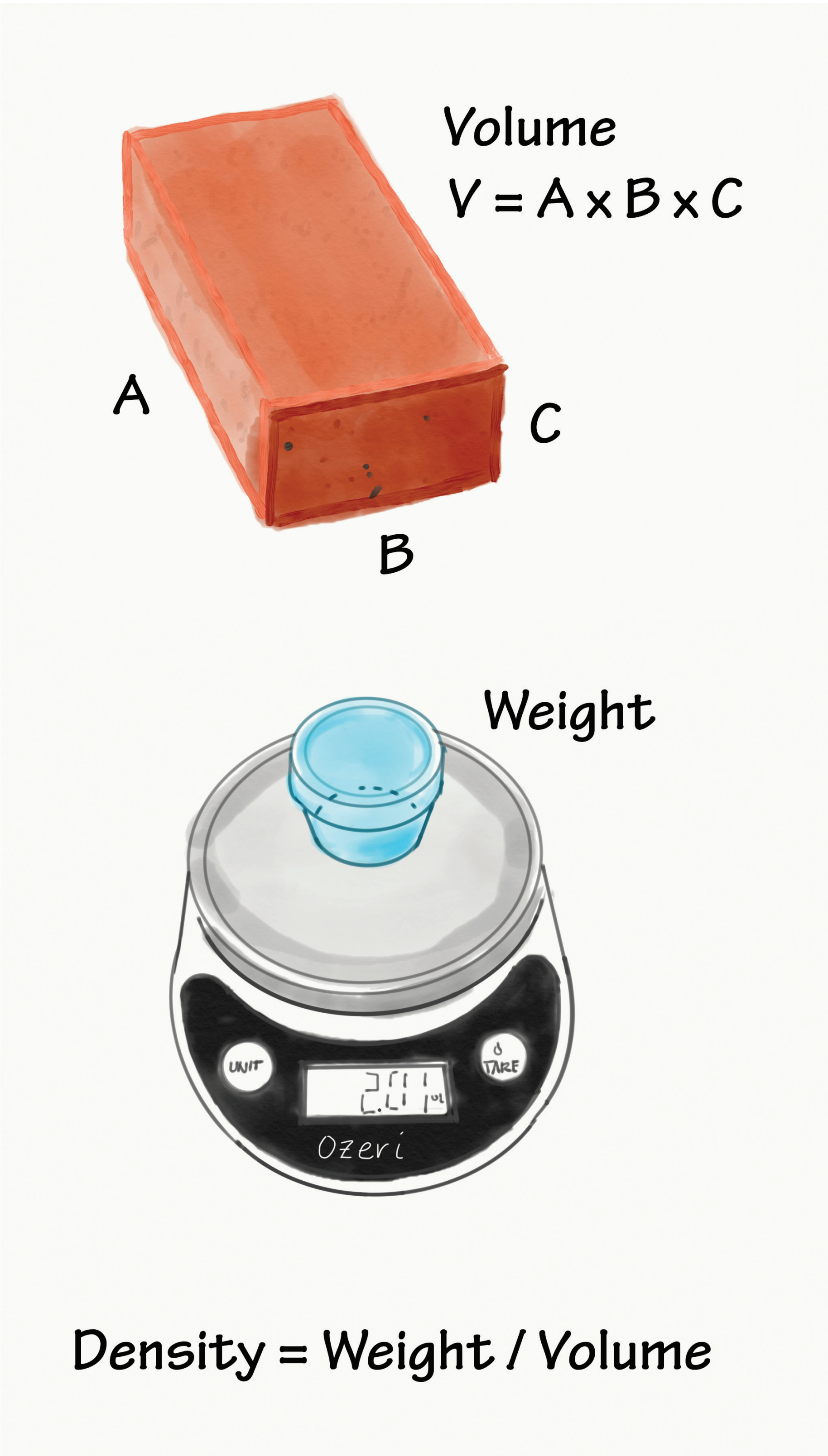


Is there more water in container A or B? Let's use the property of liquids – that they take the shape of their container – to find out!

A = B for this example ... Conservation of Mass!



SOME PROPERTIES OF STUFF



Volume

- Can be **calculated** from a **formula**, such as
  V = A x B x C
  for a rectangular solid
- Can be **measured** using **water displacement** for an irregular solid (as shown in the next example)
- Depends on the **size of the object**

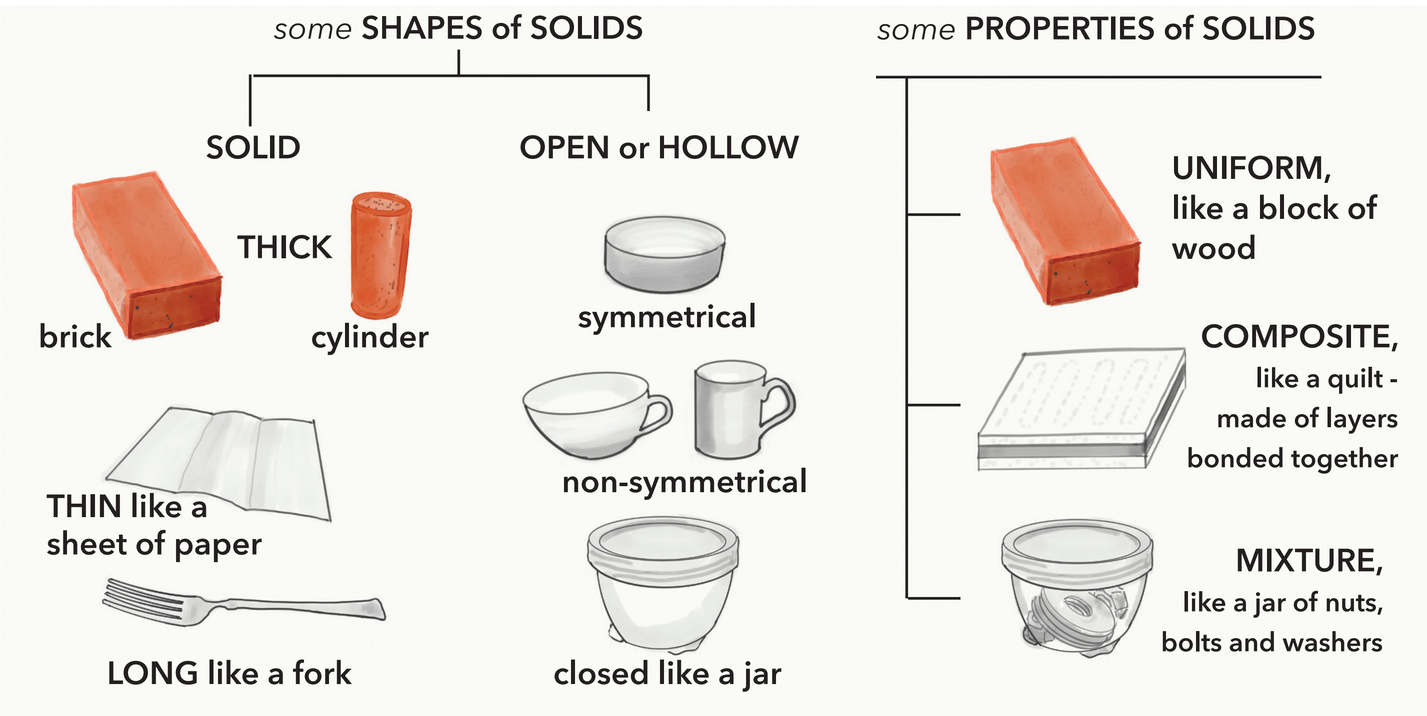
Weight

- Is normally **measured** using a scale
- Can be **calculated <u>if</u>** the **density** *and* **volume** are known.
- Depends on the **size of the object & material**

Density

- Can be **calculated** from the **Weight** divided by the **Volume**
- Is a **material property –** does <u>not</u> depend on the size of the object!

SHAPES & PROPERTIES OF SOLIDS



PART 1 - EXPLORATION - CUPS, BOWLS, FORKS

Let's begin by exploring how some common objects behave when placed in water - do they sink or float?

- forks - metal & plastic
- bowls (open, symmetric) - ceramic, styrofoam
- mugs - non-symmetric, ceramic
- plates - ceramic, styrofoam
- cork - cylindrical, solid
- glass bottle with lid - hollow, or filled with water

What did you observe?

Compare the metal and plastic forks.

- Did the material (metal or plastic) make a difference? Why do you think this might be?

Compare the bowls and mugs.

- Did the shape make a difference?
- Did the mugs with handles float as easily as the bowl without handles?
- If you splashed the water around a bit, so that water entered the bowl or mug, did it start to sink?
- Were low flat bowls more stable (harder to sink) than tall cups?
- Did the material make a difference?
- How much water did you need to take on to sink the ceramic bowl or mug?
- How much for the styrofoam bowl or cup?
- Could you get the styrofoam to sink at all?

What did you observe with closed containers?

- Could you sink the hollow container with a lid?
- If you added weight to it, could you sink it?

Based on what you've observed so far, what do you think would make the best predictor of whether an object will sink or float? Why?

- Volume, Weight, or Density (=Weight/Volume)?

PART 2 - FINDING NEUTRAL BUOYANCY

We have three potential **hypotheses** for predicting if an object will **sink** *or* **float**:

1) **Volume**
2) **Weight**
3) **Density**

Which do you think is the best? Cany you think of any observations we have so far to **rule out** one of these?

How about **volume**? If we take one of the containers with lids and put it into the water while empty, it floats. But, if we add weight, it will sink. The **volume is the same** for both cases, but the weight is different, and the equivalent density or weight divided by volume is different. **So we can rule out volume as a predictor of buoyancy.**

Ok, so how about **weight**? When we added enough weight to our container, it sank. But could we find another object that is heavier and still floats? Perhaps the ceramic bowl? Or a larger container with the same amount of weight? Yes, we can. **So, weight alone is not a predictor of buoyancy.**

That leaves **density,** which is an average **material property, and independent of size**. If you wanted to compare the weight of a solid relative to the weight of a liquid, it makes sense to use an average property like density that doesn't depend on the size of the object.

If we're trying to float something in water, doesn't it makes sense that something less dense or "lighter" than water will float, and something more dense or "heavier" than water will sink? How can we test this theory?

Let's take one of our containers, and add weight until we find "neutral buoyancy" condition. **Neutral buoyancy** is a state where an object is able to "hover" in mid water, neither rising to the top or sinking to the bottom. It's a bit difficult to achieve exactly in a small tank of water, but we can get close.

Once we achieve neutral buoyancy, we'll need to calculate the average **density** of our container, and compare it with the density of water. For that, we need to know the **weight** and the **volume**. The volume of an irregular solid can be calculated by using the principle of **water displacement**, as shown below.

Volume Calculation by Water Displacement

$$C = A + B$$

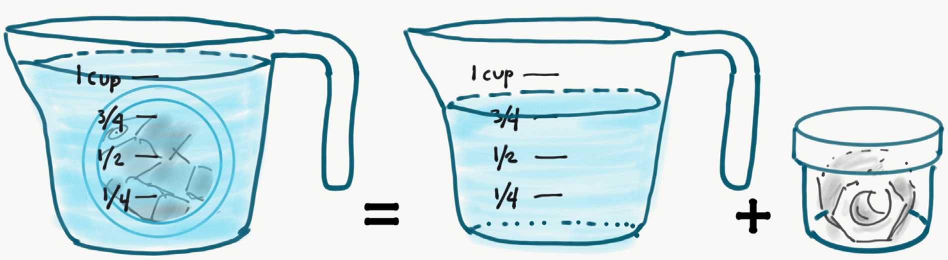
$$C - A = B$$

1 cup - 3/4 cup = 1/4 cup

Goal: Find volume of B (irregular solid)

Solution:

1) Place B in large container (weighed down)
2) Fill container with water to volume C
3) Remove B from container & measure remaining volume of water, A
4) Calculate volume of B = C - A



C = A + B

total volume — water volume — unknown volume

Note: To use the principle of water displacement to calculate the volume of your container, you must be able to cover your container completely with water. So... add weight until it sinks to the bottom of the measuring cup!

To save time, we've already calculated the volume of the lock-up containers we're using, but you can try this out for yourself. **Make note of the units** of your density calculation - oz/cup, or pounds per cubic inch. We can use conversion factors to change to more **convenient units**.

NEUTRAL BUOYANCY DATA SHEET

Some Useful Conversion Factors					
Volume	1	cup	=	14.4375	in^3
	1	cup	=	16	tbsp
	1	cup	=	48	tsp
Weight	1	lb	=	16	oz

Container Size	Volume (cups)	Volume (cu in)
1.5 oz Lock-up	0.25	3.609
6 oz Lock-up	0.9375	13.535
8 oz Lock-up	1.333	19.245

Density of Water	
1000	kg/m^3
1	g/cm^3
62.43	lb/ft^3
0.0361	**lb/in^3**
0.5776	oz/in^3
8.3391	**oz/cup**

The container volumes at left are approximate. so our calculated value of density at neutral buoyancy may be off from the density of water, but we'll be in the ballpark.

Using the largest 8 oz size Lock-up containers, let's try to find "Neutral Buoyancy". Add one washer at a time until the container sinks. Record the weight and result for that test. Then try swapping 1 nut for 1 washer (slightly lighter). Record that weight and result. Continue until you get close to a "hover" condition.

When you achieve the "hover" condition, calculate the density. Your team leader will help you. Compare this value with the density of water from the table on the top right. What do you notice? Are you close?

A	B	C	D (calculated)	E (calculated)	F (calculated)	RESULT
# Washers (count)	# Nuts (count)	Weight (oz.) (weigh)	Density (oz/cup) = C/1.333	Weight (lb) = C/16	Density (lb/in^3) =E/19.245	Float, Sink or HOVER

PART 3 – TESTING OUR HYPOTHESIS

We tested our hypothesis that **DENSITY** is able to predict whether something will sink or float. We've also speculated that if the density of an object is lighter than the density of **WATER**, it will float. If it's heavier, it will sink.

Let's test that out with some samples of wood. Each team will be given 5 samples of wood pen blanks with a range of densities. These have been calculated for you, using a measured weight and the volume formula for a rectangular solid. Your team leader will have a data sheet with the weights and volumes recorded for your reference.

If our hypothesis is correct, we'll not only be able to predict whether a sample will **sink** or **float** (or **hover** ... or be very close to hovering), but we should be able to **predict** which one will **sink** the **fastest, float** the **highest**, or **surface** the **fastest**.

So, it's off to the races for us!

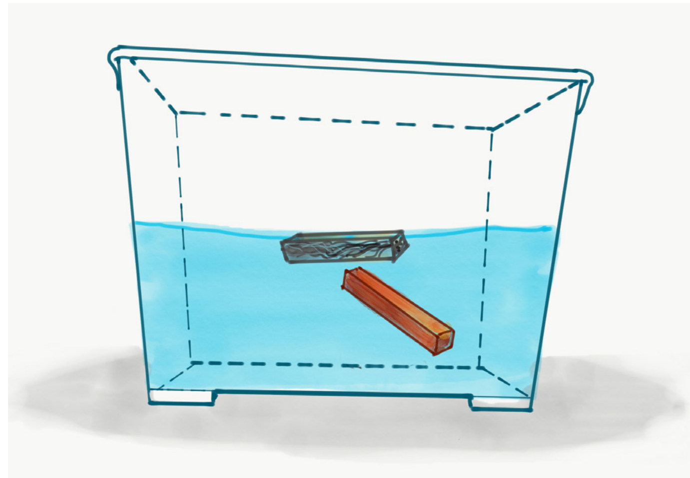
Note that materials like wood can become **"water-logged"**, which means that it can absorb some water and may become **heavier** as a result. If one of your samples does not behave as predicted, try weighing it and comparing the **weight you measured** with the **weight recorded for it. If your measurement is heavier,** the sample may have become **water-logged.** If you like, you can recalculate the density using your weight. It may be enough to tweak the density so that you would now predict it to hover or sink instead of floating.

Round 1: Test each sample at a time to see if it sinks or floats. Compare your result with the density (marked on the sample). Does it make sense?

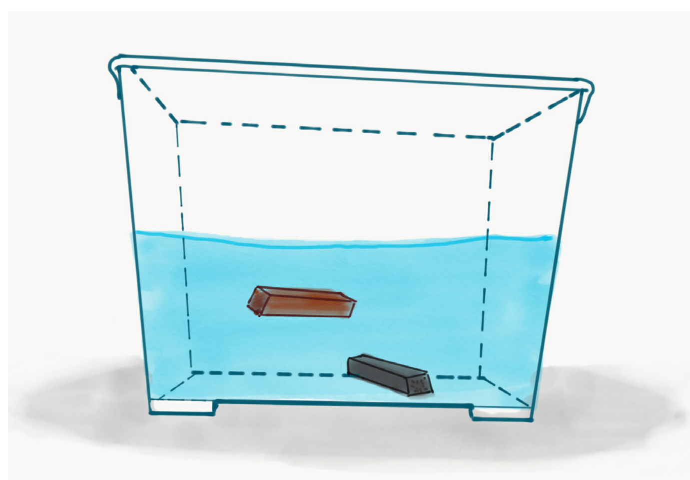
Round 2: Paired races (see figures at right). Arrange your specimens by density, lowest to highest. Run "Flotation Races" for specimens with densities < 0.036 lb/in3. Run "Sinking Races" for those with densities > 0.036.

Some specimens have calculated densities ~ 0.036. How do they behave?

What did you observe? Did density predict whether your wood samples sank or floated?



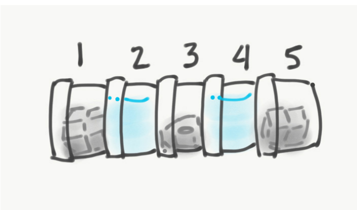
Flotation Races: If the density of your wood samples is less than water (~0.036 lb/in3), then hold them down at the bottom of the tank and release them. Which one floats to the top the fastest? The one with the lowest density?



Sinking Races: If the density of your wood samples is greater than water (~0.036 lb/in3), then hold the samples at the level of the water and release them at the same time. Which one sinks to the bottom the fastest? The one with the highest density?

PART 4 - HOW SUBMARINES SINK & SURFACE

Can you guess how submarines control their buoyancy so that they can sink or surface as needed? We're going to simulate a submarine in our next experiment!



Chambers 2 & 4 will be our ballast chambers for buoyancy control

Submarines cannot increase the volume of water they displace, so to change their density, they have to take on weight to sink, or shed weight to float. What do they have on hand that they can use to do this?

If you guessed water and air, you're right!

Submarines have to store compressed air for breathing, and they are surrounded by the water in the ocean. So all they need are ballast tanks or compartments which they can alternately flood fully or partially with water in order to sink. To surface, they displace the water in their ballast chambers with air.

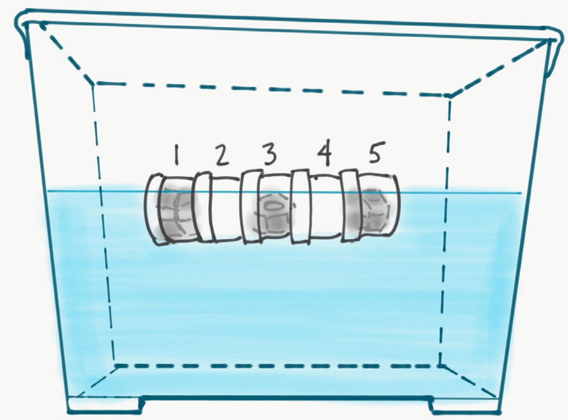
We are going to simulate this behavior using several of the small 1.5 ounce lock-up cups, as shown above. We'll load chambers 1-5 as follows:

1) 2 hex nuts
2) ballast chamber - water and/or air
3) 1 hex nut
4) ballast chamber - water and/or air
5) 2 hex nuts

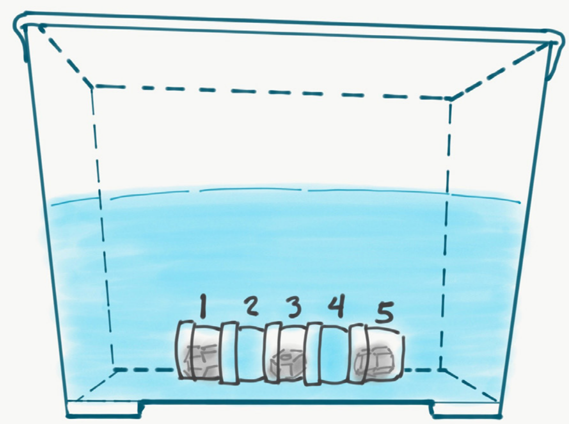
First, let's explore **Positive Buoyancy**. Fill chambers 2 & 4 with air. What do you observe? Push down on your sub. What happens?

Next let's explore **Negative Buoyancy**. Fill chambers 2 & 4 with water. What do you observe?

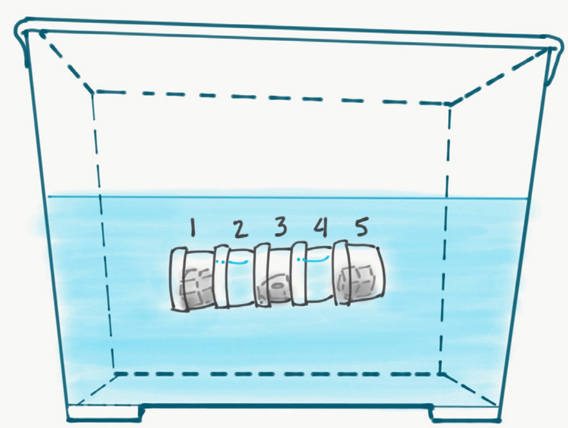
Now let's try to achieve **Neutral Buoyancy**. Experiment with how much water you need in Chambers 2 & 4 to get your sub to hover mid-water. **This is the most efficient condition for submarines to cruise at** (and for scuba divers as well!) because they don't have to expend energy to dive or surface ... only to move forward!



Positive buoyancy - air in # 2 & 4



Negative buoyancy - water in # 2 & 4



NEUTRAL buoyancy - air/water in # 2 & 4

PART 5 - DESIGNING OR SIZING A BOAT

Now let's put what we've learned so far to use. We learned that an object will float if it's "**Density**" = total weight / volume is **lighter** than the **density of water**.

Let's think about that for a minute. For a **container with a lid**, the **volume was fixed**. So you could get very close to the density of water without completely sinking the container. **Submarines** are **closed vessels** like our Lock-up cups (containers with screw on lids). They change their buoyancy by taking on water in ballast chambers, or replacing the water with air.

Now let's revisit our experience with **cups and bowls - open containers.** If we splashed water around, it could wash over the side and increase the weight. If we did this enough, we could sink it. So **what volume** would we need to calculate for a **boat**? And do we need a **margin of safety?**

We do some basic boat sizing calculations using a simple rectangular box (milk carton, etc) and a safety factor. Then we'll load them up and test them , and see where the waterline falls. Did we get it right? Do you want more margin?

We'll use our simple formula for the volume of a rectangular solid and the density of water, about 0.036 lb/in^3, to calculate a max weight or "**Sinking Weight**." This weight needs to include the weight of the box or boat itself, so if your boat is heavy, the total additional "cargo" you can add will be less than for a lighter boat.

Next you'll choose a safety factor. Try 2 to start with, then you can add more or less margin as you like.

The "Useable Weight" will be the "Sinking Weigiht" divided by your Safety Factor.

Load your boat up to your calculated Useable Weight and test it. Measure the distance of the waterline from the bottom of your boat. Is it where you thought it would be?

This should give you a basic idea of how to size a boat or other craft (surfboat, surfboard, etc.) to carry a target weight.

Container	base length (in)	base length (in)	height (in)	Volume (in^3)	Sinking Weight (lb)	Safety Factor	Useable Weight (lb) (safety factor)	Test Result (waterline locaction, in from bottom)
	A	B	C	V	Wsink	SF	Wsink/SF	waterline
milk carton	3.75	3.75	1	14.06	0.51	2	0.255	
milk carton	3.75	3.75	2	28.13	1.01	2	0.505	
milk carton	3.75	3.75	3	42.19	1.52	2	0.76	
milk carton	3.75	3.75	4	56.25	2.03	2	1.015	

BUOYANCY EXPERIMENT

Room 1 - Wood Specimens sorted by Density (lb/in3)

								Density of Water for reference --->>	0.578	8.346	0.036		
#	Speci-men	Wood	Weight (oz.)		a (in)	b (in)	c (in)	Volume (in3)	Density (oz/in3)	Density (oz/cup)	Density (lb/in3)	Predic-tion	Result
1	AS-2	Aspen	0.92		0.75	0.75	6	3.375	0.273	3.936	0.017	float	
2	TO-1	Tornillo	1.2		0.78	0.82	6	3.838	0.313	4.515	0.02	float	
3	FB-1	Flame Birch	1.34		0.75	0.76	6.1	3.477	0.385	5.564	0.024	float	
4	ST-1	Spalted Tamarind	1.76		0.87	0.9	5.4	4.228	0.416	6.01	0.026	float	
5	PA-2	Padauk	1.66		0.76	0.76	6.05	3.494	0.475	6.858	0.03	float	
6	JA-6	Jatoba	1.87		0.78	0.78	6.1	3.711	0.504	7.275	0.031	float	
7	CO-6	Cocobolo	1.94		0.78	0.79	6.05	3.728	0.52	7.513	0.033	float	
8	BL-2	Bloodwood	1.9		0.75	0.77	6	3.465	0.548	7.917	0.034	float	
9	JA-8	Jatoba	2.01		0.75	0.78	6.1	3.569	0.563	8.132	0.035	float	
10	JA-1	Jatoba	2.08		0.79	0.77	6.05	3.68	0.565	8.16	0.035	float	
11	JA-12	Jatoba	2.08		0.76	0.78	6.1	3.616	0.575	8.305	0.036	float	
12	JA-4	Jatoba	2.12		0.76	0.79	6.1	3.662	0.579	8.357	0.036	MID	
13	CU-4	Cumaru	2.05		0.76	0.76	6.1	3.523	0.582	8.4	0.036	sink	
14	JA-3	Jatoba	2.08		0.78	0.75	6.1	3.569	0.583	8.415	0.036	float	
15	CO-1	Cocobolo	1.98		0.75	0.75	6	3.375	0.587	8.47	0.037	sink	
16	CO-4	Cocobolo	1.98		0.75	0.75	6	3.375	0.587	8.47	0.037	sink	
17	BL-3	Bloodwood	2.15		0.79	0.75	6.05	3.585	0.6	8.659	0.037	sink	
18	CU-8	Cumaru	2.12		0.74	0.76	6.1	3.431	0.618	8.922	0.039	sink	
19	CU-3	Cumaru	2.15		0.74	0.76	6.1	3.431	0.627	9.048	0.039	sink	
20	CU-6	Cumaru	2.15		0.75	0.74	6.05	3.358	0.64	9.244	0.04	sink	
21	CU-7	Cumaru	2.22		0.76	0.74	6.1	3.431	0.647	9.343	0.04	sink	
22	AB-2	African Blackwood	3.21		0.89	0.88	6.25	4.895	0.656	9.468	0.041	sink	
23	IE-2	Indian Ebony	2.75		0.8	0.85	6.1	4.148	0.663	9.572	0.041	sink	
24	LV-2	Lignum Vitae (Argentine)	4.83		1.06	1.13	5.95	7.127	0.678	9.784	0.042	sink	
25	IE-1	Indian Ebony	3.1		0.9	0.82	6.15	4.539	0.683	9.861	0.043	sink	
26	CU-11	Cumaru	2.36		0.73	0.76	6.1	3.384	0.697	10.068	0.044	sink	
27	CO-7	Cocobolo	2.43		0.75	0.75	6	3.375	0.72	10.395	0.045	sink	
28	AB-4	African Blackwood	3.63		0.88	0.88	6.3	4.879	0.744	10.742	0.047	sink	
29	MO-1	Mopani	2.61		0.75	0.77	6.05	3.494	0.747	10.785	0.047	sink	
30	CO-10	Cocobolo	2.54		0.75	0.75	6	3.375	0.753	10.866	0.047	sink	

Note that the wood samples are not perfect rectangular solids, and the volume calculations can be off a litte, but not a lot.
Physics doesn't lie, so if the density doesn't predict the behavior, check the weight to see if the wood became waterlogged.
ALSO NOTE that a fine line splits floating / hovering / sinking behavior when you are close to the density of water!

BUOYANCY EXPERIMENT

Room 2 - Wood Specimens sorted by Density (lb/in3)

								Density of Water for reference --->>	0.578	8.346	0.036		
#	Speci-men	Wood	Weight (oz.)		a (in)	b (in)	c (in)	Volume (in3)	Density (oz/in3)	Density (oz/cup)	Density (lb/in3)	Predic-tion	Result
31	AS-1	Aspen	0.88		0.7	0.76	6	3.192	0.276	3.98	0.017	float	
32	TO-2	Tornillo	1.2		0.8	0.79	6.05	3.824	0.314	4.531	0.02	float	
33	FB-2	Flame Birch	1.38		0.75	0.77	6.05	3.494	0.395	5.702	0.025	float	
34	ST-2	Spalted Tamarind	1.83		0.88	0.9	5.35	4.237	0.432	6.235	0.027	float	
35	PA-1	Padauk	1.66		0.75	0.76	6.1	3.477	0.477	6.893	0.03	float	
36	JA-11	Jatoba	1.87		0.76	0.78	6.1	3.616	0.517	7.466	0.032	float	
37	BL-4	Bloodwood	1.9		0.79	0.75	6.05	3.585	0.53	7.652	0.033	float	
38	JA-2	Jatoba	2.05		0.79	0.77	6.1	3.711	0.552	7.976	0.035	float	
39	BL-1	Bloodwood	1.87		0.75	0.75	6	3.375	0.554	7.999	0.035	float	
40	JA-10	Jatoba	2.05		0.76	0.78	6.1	3.616	0.567	8.185	0.035	float	
41	CU-12	Cumaru	2.01		0.76	0.75	6.1	3.477	0.578	8.346	0.036	MID	
42	JA-9	Jatoba	2.12		0.76	0.79	6.1	3.662	0.579	8.357	0.036	float	
43	CU-1	Cumaru	1.98		0.74	0.76	6.05	3.403	0.582	8.401	0.036	sink	
44	JA-7	Jatoba	2.33		0.85	0.79	5.95	3.995	0.583	8.419	0.036	sink	
45	CO-2	Cocobolo	1.98		0.75	0.75	6	3.375	0.587	8.47	0.037	sink	
46	CU-10	Cumaru	2.05		0.74	0.76	6.1	3.431	0.598	8.627	0.037	sink	
47	CO-3	Cocobolo	2.05		0.75	0.75	6	3.375	0.607	8.769	0.038	sink	
48	CU-2	Cumaru	2.12		0.74	0.76	6.05	3.403	0.623	8.996	0.039	sink	
49	CU-9	Cumaru	2.12		0.74	0.75	6.05	3.358	0.631	9.115	0.039	sink	
50	JA-5	Jatoba	2.19		0.73	0.76	6.15	3.412	0.642	9.267	0.04	sink	
51	IE-3	Indian Ebony	2.82		0.85	0.83	6.1	4.304	0.655	9.461	0.041	sink	
52	IE-4	Indian Ebony	2.68		0.78	0.85	6.1	4.044	0.663	9.567	0.041	sink	
53	AB-1	African Blackwood	3.42		0.91	0.9	6.2	5.078	0.674	9.724	0.042	sink	
54	CO-9	Cocobolo	2.29		0.75	0.75	6	3.375	0.679	9.796	0.042	sink	
55	AB-3	African Blackwood	3.35		0.87	0.9	6.2	4.855	0.69	9.963	0.043	sink	
56	LV-1	Lignum Vitae (Argentine)	4.66		1.07	1.04	6.05	6.732	0.692	9.993	0.043	sink	
57	CU-5	Cumaru	2.36		0.76	0.74	6.05	3.403	0.694	10.014	0.043	sink	
58	CO-8	Cocobolo	2.4		0.75	0.75	6	3.375	0.711	10.267	0.044	sink	
59	CO-5	Cocobolo	2.5		0.75	0.75	6	3.375	0.741	10.694	0.046	sink	
60	MO-2	Mopani	2.89		0.8	0.79	6.05	3.824	0.756	10.912	0.047	sink	

Note that the wood samples are not perfect rectangular solids, and the volume calculations can be off a litte, but not a lot.
Physics doesn't lie, so if the density doesn't predict the behavior, check the weight to see if the wood became waterlogged.
ALSO NOTE that a fine line splits floating / hovering / sinking behavior when you are close to the density of water!

BUOYANCY EXPERIMENT

Table of All Wood Specimens sorted by Density (lb/in3) - page 1 of 2

								Density of Water for reference --->>	0.578	8.346	0.036		
#	Speci-men	Wood	Weight (oz.)		a (in)	b (in)	c (in)	Volume (in3)	Density (oz/in3)	Density (oz/cup)	Density (lb/in3)	Predic-tion	Result
1	AS-2	Aspen	0.92		0.75	0.75	6	3.375	0.273	3.936	0.017	float	
2	AS-1	Aspen	0.88		0.7	0.76	6	3.192	0.276	3.98	0.017	float	
3	TO-1	Tornillo	1.2		0.78	0.82	6	3.838	0.313	4.515	0.02	float	
4	TO-2	Tornillo	1.2		0.8	0.79	6.05	3.824	0.314	4.531	0.02	float	
5	FB-1	Flame Birch	1.34		0.75	0.76	6.1	3.477	0.385	5.564	0.024	float	
6	FB-2	Flame Birch	1.38		0.75	0.77	6.05	3.494	0.395	5.702	0.025	float	
7	ST-1	Spalted Tamarind	1.76		0.87	0.9	5.4	4.228	0.416	6.01	0.026	float	
8	ST-2	Spalted Tamarind	1.83		0.88	0.9	5.35	4.237	0.432	6.235	0.027	float	
9	PA-2	Padauk	1.66		0.76	0.76	6.05	3.494	0.475	6.858	0.03	float	
10	PA-1	Padauk	1.66		0.75	0.76	6.1	3.477	0.477	6.893	0.03	float	
11	JA-6	Jatoba	1.87		0.78	0.78	6.1	3.711	0.504	7.275	0.031	float	
12	JA-11	Jatoba	1.87		0.76	0.78	6.1	3.616	0.517	7.466	0.032	float	
13	CO-6	Cocobolo	1.94		0.78	0.79	6.05	3.728	0.52	7.513	0.033	float	
14	BL-4	Bloodwood	1.9		0.79	0.75	6.05	3.585	0.53	7.652	0.033	float	
15	BL-2	Bloodwood	1.9		0.75	0.77	6	3.465	0.548	7.917	0.034	float	
16	JA-2	Jatoba	2.05		0.79	0.77	6.1	3.711	0.552	7.976	0.035	float	
17	BL-1	Bloodwood	1.87		0.75	0.75	6	3.375	0.554	7.999	0.035	float	
18	JA-8	Jatoba	2.01		0.75	0.78	6.1	3.569	0.563	8.132	0.035	float	
19	JA-1	Jatoba	2.08		0.79	0.77	6.05	3.68	0.565	8.16	0.035	float	
20	JA-10	Jatoba	2.05		0.76	0.78	6.1	3.616	0.567	8.185	0.035	float	
21	JA-12	Jatoba	2.08		0.76	0.78	6.1	3.616	0.575	8.305	0.036	float	
22	CU-12	Cumaru	2.01		0.76	0.75	6.1	3.477	0.578	8.346	0.036	MID	
23	JA-4	Jatoba	2.12		0.76	0.79	6.1	3.662	0.579	8.357	0.036	MID	
24	JA-9	Jatoba	2.12		0.76	0.79	6.1	3.662	0.579	8.357	0.036	float	
25	CU-4	Cumaru	2.05		0.76	0.76	6.1	3.523	0.582	8.4	0.036	sink	
26	CU-1	Cumaru	1.98		0.74	0.76	6.05	3.403	0.582	8.401	0.036	sink	
27	JA-3	Jatoba	2.08		0.78	0.75	6.1	3.569	0.583	8.415	0.036	float	
28	JA-7	Jatoba	2.33		0.85	0.79	5.95	3.995	0.583	8.419	0.036	sink	
29	CO-1	Cocobolo	1.98		0.75	0.75	6	3.375	0.587	8.47	0.037	sink	
30	CO-2	Cocobolo	1.98		0.75	0.75	6	3.375	0.587	8.47	0.037	sink	

Note that the wood samples are not perfect rectangular solids, and the volume calculations can be off a litte, but not a lot.
Physics doesn't lie, so if the density doesn't predict the behavior, check the weight to see if the wood became waterlogged.
ALSO NOTE that a fine line splits floating / hovering / sinking behavior when you are close to the density of water!

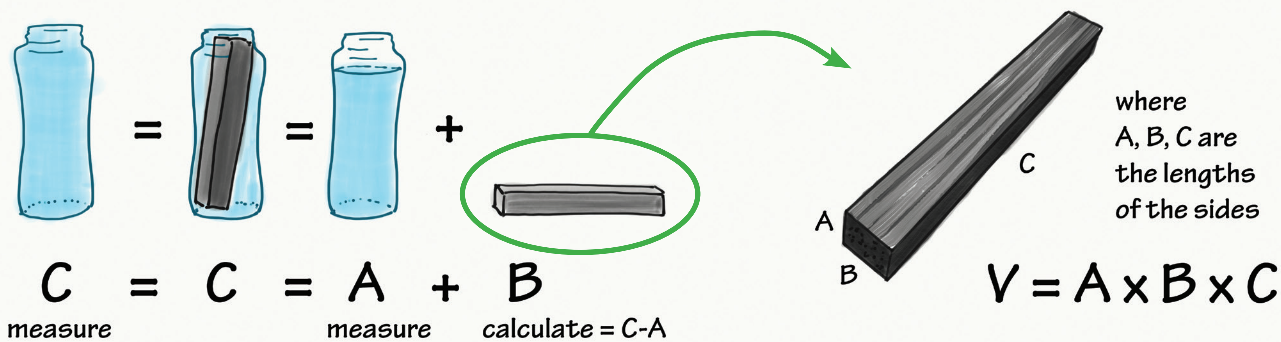
Table of All Wood Specimens sorted by Density (lb/in3) - page 2 of 2

								Density of Water for reference --->>	0.578	8.346	0.036		
#	Speci-men	Wood	Weight (oz.)		a (in)	b (in)	c (in)	Volume (in3)	Density (oz/in3)	Density (oz/cup)	Density (lb/in3)	Predic-tion	Result
31	CO-4	Cocobolo	1.98		0.75	0.75	6	3.375	0.587	8.47	0.037	sink	
32	CU-10	Cumaru	2.05		0.74	0.76	6.1	3.431	0.598	8.627	0.037	sink	
33	BL-3	Bloodwood	2.15		0.79	0.75	6.05	3.585	0.6	8.659	0.037	sink	
34	CO-3	Cocobolo	2.05		0.75	0.75	6	3.375	0.607	8.769	0.038	sink	
35	CU-8	Cumaru	2.12		0.74	0.76	6.1	3.431	0.618	8.922	0.039	sink	
36	CU-2	Cumaru	2.12		0.74	0.76	6.05	3.403	0.623	8.996	0.039	sink	
37	CU-3	Cumaru	2.15		0.74	0.76	6.1	3.431	0.627	9.048	0.039	sink	
38	CU-9	Cumaru	2.12		0.74	0.75	6.05	3.358	0.631	9.115	0.039	sink	
39	CU-6	Cumaru	2.15		0.75	0.74	6.05	3.358	0.64	9.244	0.04	sink	
40	JA-5	Jatoba	2.19		0.73	0.76	6.15	3.412	0.642	9.267	0.04	sink	
41	CU-7	Cumaru	2.22		0.76	0.74	6.1	3.431	0.647	9.343	0.04	sink	
42	IE-3	Indian Ebony	2.82		0.85	0.83	6.1	4.304	0.655	9.461	0.041	sink	
43	AB-2	African Blackwood	3.21		0.89	0.88	6.25	4.895	0.656	9.468	0.041	sink	
44	IE-4	Indian Ebony	2.68		0.78	0.85	6.1	4.044	0.663	9.567	0.041	sink	
45	IE-2	Indian Ebony	2.75		0.8	0.85	6.1	4.148	0.663	9.572	0.041	sink	
46	AB-1	African Blackwood	3.42		0.91	0.9	6.2	5.078	0.674	9.724	0.042	sink	
47	LV-2	Lignum Vitae (Argentine)	4.83		1.06	1.13	5.95	7.127	0.678	9.784	0.042	sink	
48	CO-9	Cocobolo	2.29		0.75	0.75	6	3.375	0.679	9.796	0.042	sink	
49	IE-1	Indian Ebony	3.1		0.9	0.82	6.15	4.539	0.683	9.861	0.043	sink	
50	AB-3	African Blackwood	3.35		0.87	0.9	6.2	4.855	0.69	9.963	0.043	sink	
51	LV-1	Lignum Vitae (Argentine)	4.66		1.07	1.04	6.05	6.732	0.692	9.993	0.043	sink	
52	CU-5	Cumaru	2.36		0.76	0.74	6.05	3.403	0.694	10.014	0.043	sink	
53	CU-11	Cumaru	2.36		0.73	0.76	6.1	3.384	0.697	10.068	0.044	sink	
54	CO-8	Cocobolo	2.4		0.75	0.75	6	3.375	0.711	10.267	0.044	sink	
55	CO-7	Cocobolo	2.43		0.75	0.75	6	3.375	0.72	10.395	0.045	sink	
56	CO-5	Cocobolo	2.5		0.75	0.75	6	3.375	0.741	10.694	0.046	sink	
57	AB-4	African Blackwood	3.63		0.88	0.88	6.3	4.879	0.744	10.742	0.047	sink	
58	MO-1	Mopani	2.61		0.75	0.77	6.05	3.494	0.747	10.785	0.047	sink	
59	CO-10	Cocobolo	2.54		0.75	0.75	6	3.375	0.753	10.866	0.047	sink	
60	MO-2	Mopani	2.89		0.8	0.79	6.05	3.824	0.756	10.912	0.047	sink	

PART 6 - EXTRA CREDIT - CONVERSION FACTORS

Method 1 - Volume Calculation in CUPS by Water Displacement Method

Method 2 - Volume Calculation in CUBIC INCHES by FORMULA



B = C - A = 1.81 cups - 1.5 cups = 0.31 cups

V = 0.82 in x 0.9 in x 6.1 in = 4.5 in^3

0.31 cups = 4.5 in^3

1 cup = (4.5/0.31) in3 = 14.5 in^3

Textbook:
1 cup = 14.4375 in^3
very close!

Conversion Factors are handy tools that let you work in **units** of *your* **convenience**. If someone gives you the density of water in kilograms per cubic meter, but you're designing a surfboat in inches, what do you do? Conversion factors to the rescue!

Conversion factors, when expressed as a ratio, are **equivalent to the number 1.** If you multiply any number by 1, you haven't changed the value of the number. So you treat them like you are multiplying by one, but make sure to carry the units along so that you cancel out the offending units and keep the desired ones. You can use a **Google search** or **textbook** to find one.

Curious about how these conversion factors are **created**? To generate a conversion factor, you take a "**standard**" - for example, a rectangular block of wood, and you measure or calculate the desired property by **two methods**. Since you used the same "standard", the two results are equivalent, just in **different units**.

For our buoyancy experiments, we're working with **density**, which is **weight** divided by **volume**. Our scales measure the weights in ounces (oz.), but pounds (lb.) are a more common unit. This step is easy though, because there are 16 ounces in a pound. That's the definition of an ounce.

We could use some help with **volume** however. **Cubic inches (in^3)** and cubic feet (ft^3) are common units for density. **Cups** are not. But we're working with water, and it's easy to measure water in cups. So, it would be handy to have a conversion factor that told us how many **cubic inches in a cup**.

Method 1: volume calculation by **water displacement** (see top left sketch). Two tricks here: we need a "standard" that is denser than water and will sink, and a container large enough to hold our standard. The container doesn't need to be calibrated - we can pour the water into a calibrated container to measure it. Our unknown volume, B = C-A, = 0.31 cups in this case.

Method 2: volume calculation by **formula**. Here we just need to measure the sides of our wood standard in our desired unit of inches and multiply them together. V=A x B x C = 4.5 cubic inches in this example.

Now the magic begins. We set them equal and divide one side by the other to get 1:

0.31 cups = 4.5 in^3

0.31 cups / 0.31 = 4.5 in^3 / 0.31

1 cup = 14.5 in^3 (pretty close to our textbook value of 14.4375 in^3 per cup, with measurement error!)

Table of All Wood Specimens sorted GROUP # - page 1 of 2

Density of Water for reference --->>									0.578	8.346	0.036		
#	Speci-men	Wood	Weight (oz.)		a (in)	b (in)	c (in)	Vol-ume (in3)	Density (oz/in3)	Density (oz/cup)	Density (lb/in3)	Predic-tion	Result
1	TO-1	Tornillo	1.2		0.78	0.82	6	3.838	0.313	4.515	0.02	float	
1	CO-6	Cocobolo	1.94		0.78	0.79	6.05	3.728	0.52	7.513	0.033	float	
1	JA-12	Jatoba	2.08		0.76	0.78	6.1	3.616	0.575	8.305	0.036	float	
1	CO-1	Cocobolo	1.98		0.75	0.75	6	3.375	0.587	8.47	0.037	sink	
1	AB-2	African Blackwood	3.21		0.89	0.88	6.25	4.895	0.656	9.468	0.041	sink	
1	LV-1	Lignum Vitae (Argentine)	4.66		1.07	1.04	6.05	6.732	0.692	9.993	0.043	sink	
2	TO-2	Tornillo	1.2		0.8	0.79	6.05	3.824	0.314	4.531	0.02	float	
2	BL-4	Bloodwood	1.9		0.79	0.75	6.05	3.585	0.53	7.652	0.033	float	
2	CU-12	Cumaru	2.01		0.76	0.75	6.1	3.477	0.578	8.346	0.036	MID	
2	CO-2	Cocobolo	1.98		0.75	0.75	6	3.375	0.587	8.47	0.037	sink	
2	IE-4	Indian Ebony	2.68		0.78	0.85	6.1	4.044	0.663	9.567	0.041	sink	
2	CU-5	Cumaru	2.36		0.76	0.74	6.05	3.403	0.694	10.014	0.043	sink	
3	FB-1	Flame Birch	1.34		0.75	0.76	6.1	3.477	0.385	5.564	0.024	float	
3	BL-2	Bloodwood	1.9		0.75	0.77	6	3.465	0.548	7.917	0.034	float	
3	JA-3	Jatoba	2.08		0.78	0.75	6.1	3.569	0.583	8.415	0.036	float	
3	CO-4	Cocobolo	1.98		0.75	0.75	6	3.375	0.587	8.47	0.037	sink	
3	IE-2	Indian Ebony	2.75		0.8	0.85	6.1	4.148	0.663	9.572	0.041	sink	
3	CU-11	Cumaru	2.36		0.73	0.76	6.1	3.384	0.697	10.068	0.044	sink	
4	FB-2	Flame Birch	1.38		0.75	0.77	6.05	3.494	0.395	5.702	0.025	float	
4	JA-2	Jatoba	2.05		0.79	0.77	6.1	3.711	0.552	7.976	0.035	float	
4	JA-4	Jatoba	2.12		0.76	0.79	6.1	3.662	0.579	8.357	0.036	MID	
4	CU-10	Cumaru	2.05		0.74	0.76	6.1	3.431	0.598	8.627	0.037	sink	
4	IE-3	Indian Ebony	2.82		0.85	0.83	6.1	4.304	0.655	9.461	0.041	sink	
4	CO-8	Cocobolo	2.4		0.75	0.75	6	3.375	0.711	10.267	0.044	sink	
5	ST-1	Spalted Tamarind	1.76		0.87	0.9	5.4	4.228	0.416	6.01	0.026	float	
5	JA-8	Jatoba	2.01		0.75	0.78	6.1	3.569	0.563	8.132	0.035	float	
5	JA-7	Jatoba	2.33		0.85	0.79	5.95	3.995	0.583	8.419	0.036	sink	
5	AB-1	African Blackwood	3.42		0.91	0.9	6.2	5.078	0.674	9.724	0.042	sink	
5	LV-2	Lignum Vitae (Argentine)	4.83		1.06	1.13	5.95	7.127	0.678	9.784	0.042	sink	
5	CO-7	Cocobolo	2.43		0.75	0.75	6	3.375	0.72	10.395	0.045	sink	

Table of All Wood Specimens sorted GROUP # - page 2 of 2

Density of Water for reference --->>									0.678	9.784	0.036		
#	Speci-men	Wood	Weight (oz.)		a (in)	b (in)	c (in)	Volume (in3)	Density (oz/in3)	Density (oz/cup)	Density (lb/in3)	Predic-tion	Result
6	ST-2	Spalted Tamarind	1.83		0.88	0.9	5.35	4.237	0.432	6.235	0.027	float	
6	JA-1	Jatoba	2.08		0.79	0.77	6.05	3.68	0.565	8.16	0.035	float	
6	CU-4	Cumaru	2.05		0.76	0.76	6.1	3.523	0.582	8.4	0.036	sink	
6	BL-3	Bloodwood	2.15		0.79	0.75	6.05	3.585	0.6	8.659	0.037	sink	
6	CO-3	Cocobolo	2.05		0.75	0.75	6	3.375	0.607	8.769	0.038	sink	
6	AB-4	African Blackwood	3.63		0.88	0.88	6.3	4.879	0.744	10.742	0.047	sink	
7	JA-6	Jatoba	1.87		0.78	0.78	6.1	3.711	0.504	7.275	0.031	float	
7	BL-1	Bloodwood	1.87		0.75	0.75	6	3.375	0.554	7.999	0.035	float	
7	JA-9	Jatoba	2.12		0.76	0.79	6.1	3.662	0.579	8.357	0.036	float	
7	CU-2	Cumaru	2.12		0.74	0.76	6.05	3.403	0.623	8.996	0.039	sink	
7	IE-1	Indian Ebony	3.1		0.9	0.82	6.15	4.539	0.683	9.861	0.043	sink	
7	CO-5	Cocobolo	2.5		0.75	0.75	6	3.375	0.741	10.694	0.046	sink	
8	JA-11	Jatoba	1.87		0.76	0.78	6.1	3.616	0.517	7.466	0.032	float	
8	JA-10	Jatoba	2.05		0.76	0.78	6.1	3.616	0.567	8.185	0.035	float	
8	CU-1	Cumaru	1.98		0.74	0.76	6.05	3.403	0.582	8.401	0.036	sink	
8	CO-9	Cocobolo	2.29		0.75	0.75	6	3.375	0.679	9.796	0.042	sink	
8	AB-3	African Blackwood	3.35		0.87	0.9	6.2	4.855	0.69	9.963	0.043	sink	
8	MO-2	Mopani	2.89		0.8	0.79	6.05	3.824	0.756	10.912	0.047	sink	
D-1	AS-1	Aspen	0.88		0.7	0.76	6	3.192	0.276	3.98	0.017	float	
D-1	PA-1	Padauk	1.66		0.75	0.76	6.1	3.477	0.477	6.893	0.03	float	
D-1	CO-10	Cocobolo	2.54		0.75	0.75	6	3.375	0.753	10.866	0.047	sink	
D-2	AS-2	Aspen	0.92		0.75	0.75	6	3.375	0.273	3.936	0.017	float	
D-2	PA-2	Padauk	1.66		0.76	0.76	6.05	3.494	0.475	6.858	0.03	float	
D-2	MO-1	Mopani	2.61		0.75	0.77	6.05	3.494	0.747	10.785	0.047	sink	
S	CU-8	Cumaru	2.12		0.74	0.76	6.1	3.431	0.618	8.922	0.039	sink	
S	CU-3	Cumaru	2.15		0.74	0.76	6.1	3.431	0.627	9.048	0.039	sink	
S	CU-9	Cumaru	2.12		0.74	0.75	6.05	3.358	0.631	9.115	0.039	sink	
S	CU-6	Cumaru	2.15		0.75	0.74	6.05	3.358	0.64	9.244	0.04	sink	
S	JA-5	Jatoba	2.19		0.73	0.76	6.15	3.412	0.642	9.267	0.04	sink	
S	CU-7	Cumaru	2.22		0.76	0.74	6.1	3.431	0.647	9.343	0.04	sink	

Note that the wood samples are not perfect rectangular solids, and the volume calculations can be off a litte, but not a lot.
Physics doesn't lie, so if the density doesn't predict the behavior, check the weight to see if the wood became waterlogged.
ALSO NOTE that a fine line splits floating / hovering / sinking behavior when you are close to the density of water!