Will it sink or float?

Buoyancy is one of the fundamental concepts in physics. It explains why some objects float while others sink, helping us understand the behaviour of objects in liquids and gases. This concept is crucial in designing ships, submarines, hot air balloons, and even understanding natural phenomena like how fish swim or how clouds form in the atmosphere.

The role of this learning unit is to encourage the student to think *floating* in terms of the forces involved underwater.

Unit Objectives: (1) Explain the origin of buoyant/ upthrust in fluids. (2) Measure the buoyant/ upthrust force acting on objects in fluids. (3) Explore how buoyant/ upthrust depends on the object's properties (weight, volume and density) and the fluid's density. (4) Design and conduct experiments to investigate scientific concepts, ensuring proper use of apparatus, control of variables, and accurate data collection.

Minimum Time required: 3 sessions (40 min each)

Type of Learning Unit: Laboratory

Have you ever noticed that some objects float on water while others sink? Surprisingly, sometimes heavier objects float while lighter ones sink. Can you figure out why this happens?

Some everyday objects can be taken and checked if they float or sink.

Q 1. What happens when you try to lift something underwater?

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Encourage responses like "it feels lighter," "there's less weight," or "water moves or splashes," and guide the discussion toward the idea that objects feel lighter when lifted underwater.".

Q 2. What will happen if you push a floating object, like a tennis ball or an empty bottle, underwater and then let go?

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The expected response is: "It will rise". Note if the students are mentioning "forces", direct the discussion towards that.

Do it yourself! - Task 1: Exploring forces underwater

Materials

Bucket (with water), empty plastic bottle or a container

Take a bucket filled with water and try to push the sealed (with closed cap/ air tight) empty plastic bottle into the bottom of the bucket.

Q 3. What did you observe? What forces do you think are acting on the object? Try to explain this using a diagram.

The purpose of this question is to encourage students to visually represent the problem. In this case, students may initially draw actual objects while some students may use 'arrows' to represent the forces acting in a particular direction on the object. The students may draw two diagrams, one when the object is pushed to the bottom and the hand is yet not removed, second when the hand is removed and the object floats.

If we consider an object floating on water i.e., a plastic bottle in a water bucket, where there is no movement of water, then the plastic bottle will not sink and keep floating on water.
In tug of war, when equal forces are applied in two opposite directions, the knot on the rope remains in the same position as before the forces were applied. If there is more force towards the left, the knot will move towards the left side and vice versa. The students are expected to apply the concept of "net forces" in the case of a floating object in both situations (floating and underwater).

In the case of a floating object, the 'weight of the object' is the force, which acts in the downward direction. The weight of the object is a result of Earth's gravitational force acting on the body, $W= m*g$, where 'm' is the actual mass of the body and 'g' is the acceleration due to gravity). To balance this force for a floating object there must be a buoyant/ upthrust force acting on the object that balances the weight of the object.

In the case of a floating object forcefully pushed underwater, the forces acting on it when the hand is released are not balanced. The buoyant/ upthrust force acting on the object in this case will be more than the weight of the object and it will rise. The students should be able to represent forces using directional arrows. In the next step, teachers can guide the students to represent balanced forces with equal-length arrows (in opposite directions) and unbalanced forces using unequal-length arrows.

Note that buoyancy isn't just in water—air is also a fluid, and the same principle applies to objects like birds and aeroplanes, which experience buoyant/ upthrusts in the air.

So far, we have explored the concept of buoyant/ upthrusts in fluids and understood its origin. Now, let us consider the factors that influence the buoyant/ upthrust.

Q.4. What do you think are some of the properties of the object or the fluid that can change and influence the buoyant/ upthrust force?

Let the students develop their ideas of what properties would affect the upward force/buoyant/ upthrust.
Some of the factors can be the weight of the object, the liquid used (plain water, salt water, oil, hot water, coldwater, coloured water), shape and volume of the submerged object, the volume of liquid, the material of the object (metal, plastic, wood).

The following tasks are designed to check which of these factors will affect the buoyant/ upthrust force and how. To do that we will choose one factor for one task and will try to keep the remaining factors constant.

Let us explore these questions and try to do some experiments to understand more about the buoyant/ upthrust force and why some objects float and some sink.

Materials

For Task 2, 3, 4, 5 and 6: (i) Bucket/Beaker (ii) Water, (iii) Spring balance (for weight) (iv) Same-sized small plastic containers with lid (v) Thread (vi) Small stones, (vii) Marbles viii) Clay *(for Task 3)* (ix) Objects of different shape that will sink in the water (e.g. keys, magnets etc) *(for Task 3)* (x) Aluminium foil *(for Task 5)* (xi) Salt *(for Task 6)*,

Task 2: Does the buoyant/ upthrust force depend upon the weight of the object?

A small stone sinks immediately whereas a large ship floats. This raises the question, 'Whether the buoyant/ upthrust force on an object depends upon the weight of that object or not? Let us find out.

When asked to predict, the students might judge based on the weight of the objects and respond that the lighter object will float and the heavier object will sink. Teachers should encourage students to test this idea.

To begin with, we need objects that have the same volume but different weights. This can be done by collecting containers of the same size and adding sand/stones/marbles so that each container has a different weight (but the same volume). *Add enough sand, stones, or marbles to each container so that they all sink completely in water, except for one container, which should float.*

Note: One objective of this unit is experimental design. Provide students with the necessary apparatus and objectives, and encourage them to plan and conduct the experiments.

Figure 1: Identical small plastic containers (so same volume) with different weights

Measure the weight of each of the containers with the help of a spring balance. Now submerge each of these containers in a beaker filled with water and measure their weights in water. Note down your readings in Table 1.

	Weight outside water	**Weight inside water**	**Observations**
Container 1			
Container 2			

Container 3			
Container 4 (floating)			

Table 1

While performing the task, it is important to realise that for any object there are two quantities that could be varied; **the weight** and **the volume** of that object. To study how one quantity impacts the buoyant/ upthrust, **we need to change one quantity and keep the other one constant.** In the above case, **we kept the volume of the object constant** by using the same containers and changed the weight by adding and removing different materials to the containers.

Q 5. What happened to the weights outside and inside the water?

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Q 6. Why did this happen? What can you conclude from the above observation?

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Allow students to think and discuss their ideas and help them to understand that when the object is in water, the buoyant/ upthrust acts on it in the upward direction. This buoyant/ upthrust force will then balance a part of the weight of the object. Hence we see a reduced reading for the weight of the object in the spring balance, when it is underwater. The weight of the object underwater is called apparent weight. **So, the difference in the two readings should give us the buoyant/ upthrust force acting on the object ($\text{Weight}_{\text{apparent}} = \text{Weight}_{\text{actual}} - F_{\text{buoyant/ upthrust}}$). In the observation column, the students should write this difference.**

Q 7. What is the relationship between the weight of objects in air and underwater for all the containers with the same volume but different weights? What conclusions can you draw from your observations?

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After measuring the buoyant/ upthrust force for objects of different weights, students should observe that, despite the change in weight, **the difference between actual weight and apparent weight remains the same for all containers.** This indicates that for objects with the same volume but different weights, **the buoyant/ upthrust force does not vary, meaning it is independent of the object's weight.**

While conducting the experiment, students should note that the difference is expected to be nearly constant. **Any deviations could be due to errors in measuring the object's weight, inaccurate calculations, or systematic errors from using less precise instruments.**

Q 8. Do your observations change when measuring the weight of the object in water at different depths? What conclusions can you draw from this?

It is observed that the weight of the object underwater remains the same, irrespective of the depth at which it is measured. This implies that the buoyant/ upthrust force on the object is independent of the depth of the object in water.

Task 3: Does the buoyant/ upthrust depend upon the volume of an object?

In the previous case, we explored how the buoyant/ upthrust force relates to the weight of the object. Now, let's investigate **whether the buoyant/ upthrust force changes with the volume of the object** by observing its variation for objects of different volumes.

We begin by selecting objects of the **same weight but different volumes**, then follow the same procedure as in Task 2 to measure the buoyant/ upthrust force. We can use various objects with similar weights but different shapes, adding clay to adjust their weights and make them as equal as possible.

Don't worry about achieving a perfect shape, but ensure that the objects have distinct shapes (and different volumes) and are capable of sinking in water.

Figure 2: Objects with different shapes (different volumes) but same weight.

	Weight outside water	Weight inside water	Observations
Object 1			
Object 2			
Object 3			
Object 4			

Table 2

Q 9. What is the relation between the weights of the objects *in the air and underwater* for containers with different volumes but the same weight? Is it different from the previous task where you varied the weight of the container but kept its volume constant?

Q 10. With the help of the buoyant/ upthrust force acting on the objects in the water, explain your observations.

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It is observed that for the same weight but different volumes, the measured buoyant/ upthrust force varies. Thus both the tasks imply that the **buoyant/ upthrust force depends on the volume of the object that is submerged in the liquid but not on its weight.** If one can measure the volume of the object it can be observed that the larger it is more is the buoyant/ upthrust force.

Task 4: Does the buoyant/ upthrust depend upon the density of an object?

Let's explore how the density of an object affects whether it will float or sink. **In this case, we will keep the volume constant and vary the weight, this changes the average density of the object with each weight adjustment.**

Before that let us calculate the volume of the container:
Shape of the container is: ________________________________

The shape is cylindrical (It is assumed that cylindrical-shaped containers are taken).

Volume of the container: ________________________________

Calculate using the formula: $\pi r^2 h$ (in this case the shape is cylindrical)

Take a container and standard weight measures, such as marbles. Initially as expected the empty container floats on the water. Add marbles to the container and at each stage, record the total weight of the container outside the water and calculate its density. Continue this until the container sinks.

Note here that we are only changing the weight in this case, but since the volume is not changing, the real factor influencing whether the container floats or sinks is its density.

	Weight (outside water)	**Density (Weight/ Volume)**	**Observation**
Case 1			
Case 2			
Case 3			

Table 3

Q 11. How does the change in weight affect the density of the object?

Q 12. What do you observe from the table?

For all instances where the container floated in water, its density was less than 1 g/cc, the density of water. When the container sank, its density exceeded that of water. **Any deviations may result from errors in weight measurement, inaccuracies in density calculations, or systematic errors due to less precise instruments.**

An object is either floating (where the buoyant/ upthrust balances the force of gravity) or sinking, but never a combination of both, such as partially floating or partially sinking.

For more precise measurements one can use "sand" along with marbles.

Results from all the tasks above direct us to the conclusion that an object floats in water when the buoyant/ upthrust force equals or exceeds the downward gravitational force. Quantitatively, this occurs when the object's average density is less than the density of the fluid it is immersed in.

Task 5: But when does it float?

Take a stone or marble wrapped in a 15 × 15 cm piece of aluminium foil and place it in a beaker filled with water.

Q 13. What happens to the stone or marble wrapped in aluminium foil? Why does this occur? Explain it in terms of the forces acting on the object.

The stone or marble exerts a downward force equal to its weight, while the buoyant/ upthrust force from the liquid acts on the metal foil. As observed, the stone or marble sinks, indicating that the buoyant/ upthrust force is insufficient to balance the weight of the object. As a result, the net downward force causes the object to sink to the bottom.

Now, take the same stone or marble, but instead of covering it with foil, shape the foil into a boat-like structure and place it in the water.

Q 14. What forces are acting on this object? How does the force acting on it compare to the previous arrangement with the stone or marble wrapped in foil? Discuss and explain your observations.

In this case, the stone or marble combined with the aluminum boat will exert a downward force equal to its weight, while the buoyant/ upthrust force from the liquid acts on the metal structure. As observed, the stone or marble floats, indicating that the buoyant/ upthrust force is sufficient to balance the entire weight of the object. As a result, the net upward force causes the metal boat to float.

Q 15. In both cases presented in Task 5, the materials used are the same, but the outcomes differ. Reflecting on the results from previous tasks (the dependence of buoyant/ upthrust on weight, volume, and density), consider which properties of the object affect whether it sinks or floats. Given the properties of the objects involved, which specific property is changing to produce these different results?

Students should be able to apply the results from Tasks 2, 3, and 4, regarding the dependence of buoyant/ upthrust on an object's weight and volume, to the above situations. Since the materials used are the same in both scenarios, the weight remains unchanged. The difference lies in the volume of the object, which affects the buoyant/ upthrust force (Task 3). With the weight constant, the density of the object will change, determining whether it floats or sinks.

Now, fill this boat with some more stones/marbles.

Q 16. Will the boat sink or float? Discuss and explain your reasoning.

In this case, the total weight includes both the weight of the boat and the additional stones or marbles inside it. As a result, the downward force (weight) is greater than in the previous scenario. The buoyant/ upthrust force remains unchanged, but the downward force has increased. This increased downward force now includes the weight of the boat and the water inside it.

Considering the object's properties, the weight has increased, but the volume remains the same. This means the average density of the boat has increased compared to the previous scenario. If the average density of the boat exceeds the density of water, it will sink.

What is the origin of Buoyant forces?

Fluids take the shape of the container where they are stored. If you imagine the fluid to be divided into various layers (see Fig. 1), each layer exerts a force on the layer below and also the sides of the container. Also, each layer encloses an equal area of the container.

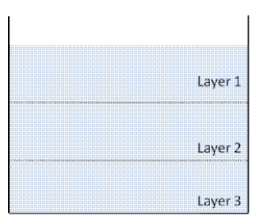

Figure 3

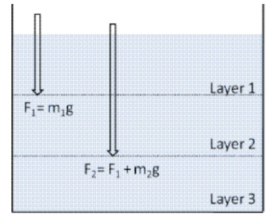

Figure 4

Q 17. Assume the mass of layers 1, 2 and 3 as m_1, m_2, and m_3 respectively. Determine the force exerted by (i) Layer 1 on layer 2 (ii) Layers 1 and 2 on layer 3. Label and illustrate these forces in Figure 1.

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Q 18. If you were to measure the *pressure* at the boundary of these layers, how do you think it would change? How could this pressure difference contribute to the buoyant/ upthrust force on the object?

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Pressure is the force acting on a surface per unit area. In a fluid, pressure is caused by the weight of the liquid above pushing down.

The pressure inside the fluid is not uniform. It increases with depth. The pressure inside a fluid increases with depth because the weight of the fluid above a given point adds to the force exerted on that point. As you go deeper, there is more fluid above, so the pressure increases due to the greater weight of the overlying fluid. Although in fluids the pressure is exerted on all sides, the vertical component is balanced, hence there is net zero pressure in that direction. For example, in the case of a plastic container in water, the pressure at the bottom of the container will always be higher than at the top.
The buoyant/ upthrust force originates because of this pressure difference. The pressure on the bottom of an object submerged in the fluid is greater than the pressure on the top, creating a net upward force which is also known as the *buoyant/ upthrust*. Encourage the students to explain this for the example they have done in Task 1.

(Optional) The change in pressure at different depths also can be demonstrated by doing a simple demonstration (see Figure 3). The demonstration is to be done by the facilitator and students can take notes. Take an empty plastic bottle and make small wholes at equal distances from bottom to top. Fill the bottle with water. Observe the distance away from the bottle where the water stream from each whole falls. One can see that the stream from the topmost hole falls at the shortest distance from the bottle, while the stream from the bottom layer takes the farthest trajectory. This implies that the pressure of fluid at the topmost hole is less than at the bottom.


Figure 5

Extended (Task 7): Does the buoyant/ upthrust depend on the liquid used?

Having explored the relationship between the buoyant/ upthrust force and the properties of the material, let's now examine how it relates to the nature of the liquid.

Do you know that scuba divers carry more weight on them when they dive in saltwater compared to when they dive in freshwater? Why do you think scuba divers do this? What is the difference between saltwater and freshwater?

Figure 6
Gibb, Natalie. (2019)

Let's try to find out.

Take two different vessels: one filled with regular water and the other with salt water (prepared by dissolving two tablespoons of salt in a glass of water). Select at least three objects and weigh them. Next, measure the weight of these objects when submerged in both liquids. This will help us determine the buoyant/ upthrust force acting on the objects in each liquid.

	Weight outside water	**Weight when submerged in normal water**	**Weight when submerged in saltwater**	**Observations (1) (for normal water)**	**Observations (2) (for Saltwater)**
Object 1					
Object 2					
Object 3					

Table 4

Q 19. What did you observe? Explain your observation.

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The densities of normal water and saltwater differ only slightly. To better observe the effect of liquid density on buoyant/ upthrust, use objects with a larger volume. Objects with greater volume experience a larger buoyant/ upthrust force, making even small differences in density more noticeable.

The buoyant/ upthrust acting on an object submerged in water depends on its volume. Similar to Task 1, the difference between the object's actual weight and its apparent weight in both normal water and saltwater will reveal the buoyant/ upthrust force. As a result, you will observe that the buoyant/ upthrust in saltwater is greater than in normal water, which will be reflected in the difference in the object's weight when submerged in each liquid.

References

- Gibb, Natalie. (2019, August 22). Buoyancy in Salt Water vs Fresh Water. Retrieved fromhttps://www.liveabout.com/buoyancy-salt-water-vs-fresh-water-2962936
- https://www.britannica.com/science/buoyancy
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