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Course Name: Physics
Unit Title: Buoyancy

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Grade Level: HS Juniors and Seniors
Concept: Factors affecting buoyancy

Goal: The goal of this learning sequence is to get students to use inquiry to understand buoyancy and learn how various factors determine the force of buoyancy.

Objectives: At the conclusion of this exercise the students will demonstrate the ability to:

1. state which of a number of factors affect buoyancy, and which do not.
2. use scientific instruments to determine the relationships between buoyancy and pertinent factors such as triple-beam balance, graduated beakers, pulleys, and computers.
3. state the nature of the relationship between the various pertinent factors and buoyancy.
4. derive the algebraic relationship between buoyancy and other pertinent factors.
5. work numeric problems using the derived relationship.
6. explain how the algebraic relationship was derived.
7. use basic formulae to calculate volumes of different standard forms (sphere, cylinder, etc.)
8. explain the basic nature of scientific research using buoyancy as an example.

Content:

I. Buoyancy is affected by the following parameters of the system –
   A. Volume of object immersed
   B. Density of immersing liquid
   C. Acceleration due to gravity

II. Buoyancy is not affected by the following parameters of the object immersed –
   A. Depth of immersion
   B. Composition
   C. Density of object
   D. Depth
   E. Weight
   F. Shape
   G. Mass

III. Mathematical relationships exists between buoyancy and pertinent factors:
   A. Buoyancy is proportional to volume of the object immersed
   B. Buoyancy is proportional to the density of the liquid in which the object is immersed
   C. Buoyancy is proportional to the ambient acceleration due to gravity

Procedure: It is assumed that students are familiar with density. Because this is an inquiry-oriented learning sequence, questions will guide the discussion throughout. Students will direct the discussion and class activities by their responses to questions and suggestions for experiments. Here are the basic questions that will be followed throughout the lesson.

<u>Day 1 (Discovery Learning, Interactive Demonstration, Inquiry Lesson):</u>

STATE LEARNING GOAL – The objective behind the next two class periods is to find the mathematical relationship between buoyancy and the factors that affect it.

<u>Discovery Learning:</u>

Students begin by examining their mental models associated with floating and sinking. They are asked to provide their understanding of boats and ships and why things with a density greater than water can float.

Q. Have any of you ever had the experience of playing with a beech ball in water?

Q. What happens when you push the beech ball under water?

Q. Have you ever lifted something heavy that is under water but doesn't float?

Q. What happens when you lift the stone or whatever it is out of the water?

Q. Where does this force come from?

So, you've not had this experience? Then try this! (Give students beaker of water and blocks of wood and metal.) Take these objects and see how they behave in water (some sink, others float). Have students replicate situations such as those above?

Q. Does anyone know what we call this mysterious force? (buoyancy)

Interactive Demonstration:

Q. How do you measure the buoyant force experienced by an object submerged in a liquid?

Note: Place weight on spring balance into water.

Q. What is being measured this time?

Q. Have you noticed that there is a difference in air & submerged weight? Why?

Q. How can we calculate the buoyant force of the liquid? Using force diagrams –

In liquid:

$$\Sigma F = 0$$

$$F_b + T_\ell + mg = 0$$

In air:

$$\Sigma F = 0$$

$$T_a + mg = 0$$

equating

$$F_b + T_\ell + mg = T_a + mg$$

$$F_b = T_a - T_\ell$$

Q. If this weight is submerged only partially in the liquid, how can we measure and calculate the buoyant force exerted on it?

Note: Observe that the smaller the submersion, the smaller the buoyant force.

Note: Float wood on surface of water.

Q. What is the buoyant force exerted on the wood by the water?

Note: Slowly immerse the wood on a scale into the water. Give the weight until 0.

Q. Do you understand why the scale reads zero?

Note: $T_a = F_b$ $(F_b = T_a - 0)$

Inquiry Lesson:

Q. What physical factors might affect the buoyant force exerted on a body?

Note: possible factors: density of liquid, orientation, depth, weight or composition, orientation, shape, volume or size, etc.

Q. Is the buoyant force experienced by a submerged object related to its shape?

Note: Test with a clay bob, deforming after first test.

Q. Does the buoyant force experience by a submerged object depend on its orientation?

Note: Test with a block of aluminum oriented along three different axes.

Q. Is the buoyant force experienced by a submerged object related to its size?

Note: Test using two different sized objects of same weight (plexi cyl & 100g weight).

Q. Is the buoyant force exerted on a body dependent upon the weight of a body?

Note: Test with aluminum and copper ingots of identical volume.

Q. From what you've seen thus far, can you tell me if the buoyant force depends upon the density of a body?

Q. Is the buoyant force exerted by a liquid dependent upon the depth?

Note: Check buoyant force at varying depths.

Q. Is the buoyant force exerted by a liquid dependent upon the type of liquid?

Note: Test using fresh and then salt water.

Day 2 (Jigsaw version of Bounded Inquiry Lab – one group finds relationship between buoyancy and density of liquid and other groups find relationship between buoyancy volume of object:

Summary of findings thus far --

F_b depends upon:	F_b DOES NOT depend upon:
density of liquid	density of object
volume of object	depth of object
	shape of object
	weight of object
	mass of object

Working relationships:

$$F_b = T_a - T_\ell$$

$$F_b = T_a \text{ (floating)}$$

Q. How does the buoyant force depend upon the volume of the object?

Q. How does the buoyant force depend upon the density of the liquid?

<u>Inquiry Lab:</u> Students design and perform experiments to find proportionalities between F_b, V, and ρ_ℓ. They experimentally determine that F_b is proportional to V as well as to ρ_ℓ. Students then speculate as to the nature of the relationship between all three variables:

$$F_b = a\rho_\ell V + \sigma \quad ?$$

$$F_b = a\rho_\ell + cV + e \qquad ?$$

Students find, give, and explain actual mathematical relationship, $F_b = \rho_\ell Vg$

<u>Real-world Applications:</u>

Follow-up Questions & Problems

Q. Which of the above represents the true relationship between variables?

Q. Why do objects experience a buoyant force?

Q. Will objects lying on the bottom of a fluid experience a buoyant force?

Q. Is it true that light objects float while heavy objects sink? (penny versus a block of wood)

Q. What conditions of density determine whether or not an object will float in a fluid?

Q. How can you measure the buoyant force when a piece of wood is completely submerged in water?

Q. How much buoyant force is exerted on a 14-inch diameter basketball immersed in pure water?

Q. You are on an unnamed planet and you want to find the acceleration due to gravity. A 3-cm diameter aluminum ball immersed in pure liquid water experiences a buoyant force of 0.15N. What is the acceleration due to gravity?

Q. An object with a volume of 10 cm^3 experiences a force of 0.5N on the surface of the Earth. What is the density of the fluid?

<u>Hypothetical Explanation:</u>

Q. Where does the buoyant force come from?

Students study pressure at depth and find $P = \rho_\ell gh$. The study of a hypothetical cube shows that the difference in forces ($F = PA$) accounts for buoyant force.

Materials:

Triple-beam balance Pyknometer Computer w/ Graph Analysis Volume formulae for regular polygons	String Vernier caliper Clay Beakers Miscellaneous objects with different densities and shapes	Beakers Alcohol Olive oil Water and Salt Honey Hydrometer