Archimedes, A Gold Thief and Buoyancy

by Larry "Harris" Taylor, Ph.D..

Once upon a time (the 3rd century B.C.) there was a very wealthy king. Like most kings, Hiero of Syracuse (on the island of modern day Sicily) wore a crown as a symbol of his authority. Over the years, Hiero was made aware that his Royal Goldsmith (who made his crown from Hiero's treasury) was living a lifestyle that was beyond his means. Hiero suspected that the Royal Goldsmith was using royal gold, intended for the royal crown, to augment his personal wealth. The goldsmith was rumored to be preparing the crowns with a cheaper alloy (using a silver-gold mix) than pure gold. No one using 3 rd century B.C. technology knew how to prove or disprove the speculation that the Royal Goldsmith was stealing from the crown.

The problem of determining the gold content of the royal crown was given to Archimedes, a noted Greek mathematician and natural philosopher. Needles to say, this was not a trivial problem! Archimedes knew that silver was less dense than gold, but did not know any way of determining the relative the density (mass/volume) of an irregularly shaped crown, The weight could be determined using a balance or scale, but the only way known to determine volume, using the geometry of the day, was to beat the crown into a solid sphere or cube. Since Hiero had specified that damage to the crown would be viewed with less than enthusiasm, Archimedes did not wish to risk the king's wrath by pounding the crown into a cube and hoping that post-analysis it could be made all better again. While in the public baths, Archimedes observed that the level of water rose in the tub when he entered the bath. He realized this was the solution to his problem and supposedly, in his excitement, he leaped up and ran naked through the streets back to his laboratory screaming Eureka, Eureka! (I've got it! I've got it!)

Later, he demonstrated to Hiero and his court how the amount of water overflowing a tub could be used to measure a volume. His calculations indicated the goldsmith was, indeed, an embezzler. History does not record the fate of the unscrupulous artisan.

Archimedes observation has been formalized into Archimedes Principle:

An object partially or wholly immersed in a fluid, is buoyed up by a force equal to the weight of the fluid displaced by the object.

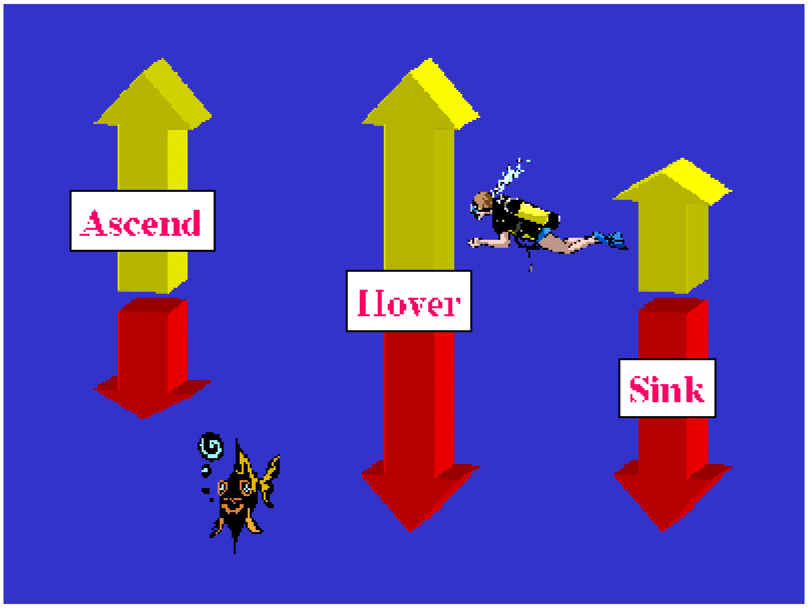
Translation: Objects more dense than water (like lead) will sink; objects less dense than water (like cork) will float; objects of the same density will remain at the same level (hover) and neither sink nor float. Objects that sink are frequently termed *negatively buoyant*. Objects that float are termed *positively buoyant*. Objects that stay stationary at depth are said to be *neutrally buoyant*.

Weight is a downward force (gravity acting on mass); buoyancy is an upward force. If these two forces are balanced, then so-called neutral buoyancy (object hovers) is achieved. If they are not balanced, the object immersed will either sink (weight greater than upward buoyant force) or float (weight less than upward buoyant force).

NOTE: As with weight and mass, divers commonly are imprecise in the use of the term buoyancy. Rigorously, buoyancy is defined as ONLY an upward force directed against the force of weight. Although commonly used in the diving community, the terms "neutrally buoyant" and "negatively buoyant" are rigorously improper; the term "positively buoyant" is redundant. Buoyancy is much easier to understand if one only considers balancing an upward force (buoyancy) and a downward force (weight). In this scheme, there is no positive or negative. We will use the term "hover" to refer to the so-called "neutrally buoyant" state. Thus, an object will float, hover or sink. If weight is greater than buoyancy, the object sinks. If buoyancy is greater than weight, the object rises. If weight and buoyancy are identical, then the object hovers (is weightless).

EXAMPLE: When a helicopter "hovers." (Remains stationary and neither rises or sinks) the helicopter has exactly balanced the downward force of weight with the upward force of lift supplied by the turning rotor. A diver "hovers" by balancing the downward force of weight with the upward force of buoyancy.

For the diver, the force of buoyancy (yellow arrow, below) ALWAYS acts to move the diver (immersed object) towards the surface. Mass (red arrow, below) ALWAYS acts to move the diver (immersed object) towards the bottom. These forces are either balanced (identical) or unbalanced. If they are NOT balanced (the ideal "hovering" or weightless condition), then the diver MUST expend energy to maintain a horizontal steady state.



Buoyancy Largest = Ascend
Forces Balanced = Hover
Mass Largest = Sink

Most buoyancy issues (either solving buoyancy physics problems or in-water diving) can be understood by simply determining the relationship between forces acting either up or down.

Buoyancy-type problems involve three factors: the mass of the object being submerged, the volume of the object submerged, and the density of the liquid involved in the problem.

Any two of these factors can be used to determine the third. The amount of an object floating that is submerged can also be calculated simply by finding the ratio of densities. For example, an object with a density of 0.965 $^{g}/_{mL}$ in water floats and will be:

$$\frac{0.965\,^{g}/_{mL}}{1.000\,^{g}/_{mL}} \times 100\% = \textbf{96.5\% submerged}$$

Name____ Date________________

<u>Archimedes in Action</u>

Part A. Short Answer Questions for follow-up:

1. What does the word "buoyancy" really mean (in <u>your</u> own words)?

2. What does it mean if something is "positively buoyant"?

3. What does it mean if something is "negatively buoyant"?

4. What does it mean if something is "neutrally buoyant"?

5. Describe, in your own words, what Archimedes did and what he found. How did he prove the thief guilty?____
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6. Were there any words you did not know the definition for and had to go look up or ask someone what it meant? Write them below (you don't have to include what they mean).

7. Did you understand the article? YES or NO (circle one)

Part B. Show all your work for the following problems!

8. A log weighing 6000 kg measures 1.0 m x 3.0 m x 2.0 m. Will this object sink or float in seawater (density = 1.0256 kg/L)? (Remember, 1 L = 1m^3)

9. How much of the log in question #7 will be submerged?

10. A wet suited diver weighs 74 kg with gear. The diver has a volume of 80 L. How much extra mass should the diver wear for diving in seawater that has a density of 1.026 kg/L?