Enhanced Inquiry Approach for Buoyancy

PHY 312 Reflection
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As physics teachers, we rarely have the opportunity to explain *why* something happens. In most cases we, as scientists, merely describe what happens. We describe how things fall with kinematics equations such as

$$d = d_o + v_o t + \frac{1}{2}at^2$$

An "enhanced inquiry approach" will go beyond the mere process of identifying laws, and will move ahead to achieve a deeper understanding of why a particular law or phenomenon exists.

Buoyancy provides a rare opportunity for teacher (and preferably their students) to derive an authentic explanation – where the buoyant force comes from and why objects float. As physics teachers, you can use the study of buoyancy to go beyond even the usual inquiry process, and strive for understanding in addition to constructed knowledge.

Mere Belief (a formula if taught didactically):

$$F_b = \rho_f V g$$

Constructed Knowledge (a law derived through experimentation)

$$F_b \propto V \text{ and } F_b \propto \rho_f \text{ implies } F_b = k\rho_f V$$

where it can be show experimentally that k equals g.

Understanding (realizing why the buoyant force exists)

Experimental work shows that the pressure at depth d in a liquid of constant density, ρ_f, is given by the relation $P_d = \rho_f g d$. Greater depth implies greater pressure. *Hypothesize* that F_b comes from a difference in the pressure exerted on the top and bottom surfaces of an immersed object, say, a cube. The top of the cube is at a depth of, say, *d.* The bottom of the cube is at a depth of $d + l$. The depth difference top-to-bottom is therefore give by *l,* the vertical dimension of the cube, alone. Now, because pressure times surface area (of top or bottom, l^2) is equal to the force exerted by the fluid at depth *d,* the force at the top will be given by pressure there times the surface area at that level. So it is at the bottom of the cube. Hence, the pressure difference top to bottom will be given by

$$\Delta P_{top-to-bottm} = \rho_f g l$$

Then, because pressure on the top and bottom times surface area equals force,

$$\Delta F_b = \Delta P \bullet A = \Delta P \bullet l^2 = \rho_f g l^3 = \rho_f g V$$

which is the form of the relationship derived experimentally for the nature of the buoyant force.

The hypothesis that buoyancy is produced by differences in the pressure exerted on the top and bottom of an immerse object allows for the accurate derivation of the buoyant force. This provides solid support for the hypothesis, and allows for a meaningful explanation of the cause of the buoyant force – something not ordinarily achieved with the normal inquiry approach. Only this enhanced approach to inquiry to produce true conceptual understanding.

Now, consider the role of density of objects that rise, sink, or are neutrally buoyant when totally immersed in a fluid medium. Note first the following conditions:

an object floats when $|F_b| > |F_g|$;

an object sinks when $|F_b| < |F_g|$; and

an object is neutrally buoyant when $|F_b| = |F_g|$.

Let us now consider this critical boundary condition first to help understand the role the relative density plays in the question of floating and sinking.

From the above, we know that $F_b = \rho_f Vg$. We also know that $F_g = mg = \rho_o Vg$. Equating yields the following condition for neutral buoyancy:

$$\rho_f Vg = \rho_o Vg \text{ (neutral buoyancy)}$$

from which it is derived after canceling Vg on both sides of the equation

$$\rho_f = \rho_o \text{ (neutral buoyancy)}$$

Hence, if an object is to be neutrally buoyant, its density must be equal to that of the medium in which it is immersed. By the same line of reasoning (merely replacing the equality sign with > for floating objects and < for sinking objects), we find that an object floats in a medium when its density is less than that of the medium in which it is immersed, and that an object sinks in a medium when its density is greater than that of the medium in which it is immersed. That is, $\rho_f > \rho_o$ represents the floating condition, and $\rho_f < \rho_o$ represents the sinking condition.

So, Archimedes' condition (an normally stated) is satisfied. That is, if an object displaces a volume of a fluid which weighs more than the object itself (e.g., its density is less than that of the medium), then there will be a net upward force and the object will float, and visa versa.

When students of physics comprehend the nature of buoyancy to this degree, they can be said to possess understanding, and not only knowledge or mere belief.

- Does the traditional study of the phenomenon lead to belief, knowledge, or understanding?
- Does the inquiry approach lead to belief, knowledge, or understanding?
- Does the enhanced inquiry approach lead to belief, knowledge, or understanding?
- What does this say about the nature of our educational practices?
- How will/should you teach physics when you have the opportunity?

Understanding comes at a price; depth of coverage requires less breadth of coverage.