Key Concepts

Chapter 5

Archimedes' principle: F_B = weight of the displaced fluid

Buoyancy

Newton's laws

$F_B = \rho_{\text{fluid}} g V_{\text{submerged}}$

Hydrostatics

A raft of area 2 m^2 floats on water with the bottom 2 cm of the raft submerged. Assuming a thick raft, to what depth is the raft submerged when a brick of mass 3 kg is placed on top of the raft?

1) Determine the volume of the submerged part of the raft.

$V_{\text{submerged}} = \text{area} \times \text{height} = (2\text{ m}^2) \times (0.02\text{ m}) = 0.04\text{ m}^3$

The part of the raft that is submerged has the shape of a rectangular prism with a height of 2 cm (0.02 m) and a base area of 2 m^2. In any buoyancy problem, the volume of the portion of the object that is submerged is a useful quantity, so this is a good starting point even if you do not know where to begin.

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2) Determine the buoyant force on the raft.

$F_B = \rho_{\text{fluid}} g V_{\text{submerged}}$

$F_B = (1{,}000\text{ kg/m}^3)(9.8\text{ m/s}^2)(0.04\text{ m}^3) = 392\text{ N}$

The buoyant force is given by the formula $F_B = \rho_{\text{fluid}} g V_{\text{submerged}}$. Because the raft is floating (not sinking), the net force on the raft must be zero. This means that the buoyant force equals the weight of the raft. This is the connection that most people will not make on Test Day.

MCAT Pitfall: *The buoyant force depends on the density of the fluid,* not *the density of the object. Also, it depends on the submerged volume of the object,* not *the total volume (unless the whole object is submerged).*

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3) Find the new buoyant force with the added mass.

$F_B = \text{weight}_{\text{raft}} + \text{weight}_{\text{brick}} = 392 + m_{\text{brick}} g = 392 + (3)(9.8) = 421.4\text{ N}$

This buoyant force is the force required to support the weight of the raft and the brick.

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4) Find the volume of the submerged part of the raft.

$F_B = \rho_{\text{fluid}} g V_{\text{submerged}}$

$$V_{\text{submerged}} = \frac{F_B}{(\rho_{\text{fluid}} g)} = \frac{(421.4\text{ N})}{(1{,}000\text{ kg/m}^3 \times 9.8\text{ m/s}^2)} = 0.043\text{ m}^3$$

Use the buoyant force found in step 3 in the buoyancy formula. The only unknown is the new submerged volume.

Takeaways

When confronting this problem, it may seem that not enough information has been given to you because you are not given the mass, density, or total size of the raft. You must use two commonly forgotten facts about buoyancy: (1) If something is floating, the buoyant force must equal the weight of that object, and (2) the buoyant force depends on the volume of the part of the object that is submerged.

When in doubt on how to start a buoyancy problem, write the buoyant force formula and see where it leads you. Remember that the buoyant force is a force just like any other: Draw it in free-body diagrams and apply Newton's laws.

5) Find the submerged depth of the raft.

$$V = Az$$

$$z = \frac{V}{A} = \frac{(0.043\ \text{m}^3)}{(2\ \text{m}^2)} = 2.15\ \text{cm}$$

Once again, we are considering the volume of a rectangular prism with a base area of 2 m^2.

Similar Questions

1) A block of mass 5 kg and density 3 g/cm^3 is hung from a string while submerged in water. What is the tension in the string?
2) A cube of side length 3 cm floats in water ($\rho = 1\ g/cm^3$) with 1 cm floating above the water. What is the density of this cube?
3) A piece of cork ($\rho = 0.2\ g/cm^3$) with mass 5 g is held underwater. When the cork is released, what is its initial acceleration?

Things to Watch Out For

A very common pitfall for buoyancy problems is to try to use the density of the object to determine the buoyant force.