A 6.15-kg Piece Of Wood (SG = 0.50) Floats On Water. What Minimum Mass Of Lead (SG = 11.3), Hung From

Understanding the Floating and Buoyancy Principles in Fluids

A 6.15-kg Piece Of Wood (SG = 0.50) Floats On Water. What Minimum Mass Of Lead (SG = 11.3), Hung From offers an interesting exploration of buoyancy, density, and the physics behind floating objects. When objects are placed in a fluid, their ability to float depends on their density relative to the fluid and the principle of buoyancy, which states that an object submerged in a fluid experiences an upward force equal to the weight of the displaced fluid. In this article, we will analyze how to determine the minimum mass of lead required to make a wooden block sink or just stay afloat when attached to it, considering their specific gravities and the principles governing buoyant force.

Fundamentals of Density, Specific Gravity, and Buoyancy

What Is Specific Gravity?

Specific gravity (SG) is a dimensionless number that compares the density of a substance to the density of water at a specified temperature (usually 4°C, where water's density is approximately 1000 kg/m³). It is calculated as:

- SG = (Density of substance) / (Density of water)

For example:

- Wood with SG = 0.50 means its density is half that of water (~500 kg/m³).
- Lead with SG = 11.3 indicates a density 11.3 times that of water (~11,300 kg/m³).

Buoyant Force and Archimedes' Principle

Archimedes' principle states:

> The buoyant force (F_b) acting on an object submerged in a fluid is equal to the weight of the displaced fluid:

- $F_b = \rho_{fluid} \times g \times V_{displaced}$

where:

- ρ_{fluid} = density of the fluid (water in this case),
- g = acceleration due to gravity (~9.81 m/s^2),
- $V_{displaced}$ = volume of fluid displaced.

The object will float if its weight is balanced or less than the buoyant force; it will sink if its weight exceeds this force.

Analyzing the Wooden Block

Calculating the Volume of the Wooden Piece

Given:

- Mass of wood (m_{wood}) = 6.15 kg
- Specific gravity of wood (SG_{wood}) = 0.50

Since SG relates to density:

- $\rho_{wood} = SG_{wood} \times \rho_{water} = 0.50 \times 1000\ kg/m^3 = 500\ kg/m^3$

The volume of the wooden piece:

- $V_{wood} = m_{wood} / \rho_{wood} = 6.15\ kg / 500\ kg/m^3 = 0.0123\ m^3$

The Buoyant Force Acting on the Wooden Block

When floating:

- The weight of the wooden block (W_{wood}) = $m_{wood} \times g = 6.15\ kg \times 9.81\ m/s^2 \approx 60.4\ N$

- The buoyant force equals this weight when floating:

$F_b = W_{wood}$

- The volume of water displaced:

$V_{displaced\_water} = V_{wood} = 0.0123\ m^3$

- The weight of displaced water:

$W\_displaced\_water = \rho\_water \times g \times V\_displaced\_water = 1000\ kg/m^3 \times 9.81\ m/s^2 \times 0.0123\ m^3 \approx 120.8\ N$

Since the buoyant force (≈120.8 N) exceeds the weight, the wooden piece floats, with some portion submerged.

Note: For a floating object, the submerged volume is less than the total volume if its density is less than water’s.

Adding Lead: The Goal and Considerations

Objective: Determining the Minimum Mass of Lead Needed

If the wooden piece is to be made to sink or just remain submerged with a lead weight attached, we need to consider:

- The additional weight (lead mass) must be enough to overcome buoyancy.
- The lead is hung from the wooden piece, possibly at the center or edge, but for simplicity, assume it adds directly to the weight.

Understanding the Effect of the Lead Mass

- When lead is hung from the wooden piece, the total weight becomes:

$W\_total = W\_wood + W\_lead = (m\_wood + m\_lead) \times g$

- To just make the wooden piece sink, the total weight must be at least equal to the buoyant force when fully submerged:

$W\_total \geq \rho\_water \times g \times V\_wood$

- To float with the lead attached, the combined weight should be greater than the buoyant force acting on the displaced volume.

Calculating the Minimum Mass of Lead

Scenario 1: Making the Wooden Piece Sink

In this case, the goal is to add enough lead so that the total weight exceeds the buoyant force when fully submerged.

- The total weight:

$W_{total} = (m_{wood} + m_{lead}) \times g$

- The total displaced water weight (for full submersion):

$W_{displaced\_water} = \rho_{water} \times g \times V_{wood}$

- Setting:

$W_{total} \geq W_{displaced\_water}$

$\Rightarrow (m_{wood} + m_{lead}) \times g \geq \rho_{water} \times g \times V_{wood}$

$\Rightarrow m_{wood} + m_{lead} \geq \rho_{water} \times V_{wood}$

$\Rightarrow m_{lead} \geq (\rho_{water} \times V_{wood}) - m_{wood}$

Calculating:

- $\rho_{water} \times V_{wood} = 1000\ kg/m^3 \times 0.0123\ m^3 = 12.3\ kg$

- $m_{wood} = 6.15\ kg$

Therefore:

$m_{lead} \geq 12.3\ kg - 6.15\ kg = 6.15\ kg$

Result: The minimum mass of lead required to sink the wooden piece is approximately 6.15 kg.

Scenario 2: Achieving Equilibrium at the Surface (Just Floating with Lead)

Alternatively, if the goal is to just make the wooden piece float with the lead attached (i.e., the total weight equals the buoyant force at equilibrium), then:

- The total weight equals the weight of displaced water:

$(6.15\ kg + m_{lead}) \times g = \rho_{water} \times g \times V_{wood}$

- Simplify:

$6.15\ kg + m_{lead} = 12.3\ kg$

$\Rightarrow m_{lead} = 12.3\ kg - 6.15\ kg = 6.15\ kg$

Same as the sink condition, indicating that approximately 6.15 kg of lead is needed to just make the wooden piece sink or stay submerged fully.

Impact of Specific Gravity of Lead on the Calculation

Since lead has a high specific gravity (SG = 11.3), its density:

- $\rho_{lead} = SG \times \rho_{water} = 11.3 \times 1000\ kg/m^3 = 11{,}300\ kg/m^3$

This high density means:

- The volume of lead needed (to reach 6.15 kg):

$V_{lead} = m_{lead} / \rho_{lead} = 6.15\ kg / 11{,}300\ kg/m^3 \approx 0.000544\ m^3$

- The volume of lead is very small compared to the volume of the wooden block, emphasizing the efficiency of dense materials like lead in adding weight with minimal volume.

Practical Considerations and Applications

Why Use Lead for Weight Addition?

- High density allows small volumes to carry significant mass.
- Commonly used in ballast, counterweights, and fishing weights.
- Minimal space requirement makes it ideal for precise weight adjustments.

Safety and Handling of Lead

- Lead is toxic; handling should be done with care.
- Proper disposal and safety measures are essential.

Summary of Key Calculations and Findings

- Volume of wooden piece: approximately $0.0123\ m^3$.

- Minimum lead mass to sink the wooden piece: approximately 6.15 kg.
- Volume of lead needed: approximately 0.000544 m^3.
- The high specific gravity of lead allows for effective weight addition with minimal volume.

Conclusion

Understanding the principles of buoyancy, density, and specific gravity is essential for solving problems involving floating objects and weight addition. In the case of a 6.15-kg wooden block with SG = 0.50 floating on water, about 6.15 kg of lead with SG = 11.3 is required to just make it sink or stay submerged when hung from it. This calculation underscores the importance of material density and volume considerations in practical applications such as designing floating structures, ballast systems, or weight balancing.

By mastering these concepts, engineers and students can effectively analyze and design systems involving floating objects, ensuring stability, safety, and optimal performance in fluid environments.

Frequently Asked Questions

What is the minimum mass of lead required to just sink a 6.15-kg piece of wood with a specific gravity of 0.50 when hung from it?

The minimum mass of lead needed is approximately 1.384 kg. This is calculated by balancing the buoyant force and the weight of the wood plus the lead, considering the specific gravities and the volume of the wood.

How does the specific gravity of the wood affect the minimum mass of lead needed to sink it?

A lower specific gravity (less dense than water) means the wood floats more easily, requiring a larger mass of lead to sink it. Conversely, higher specific gravity reduces the amount of lead needed.

Why is the specific gravity of lead (SG = 11.3) important in calculating the minimum mass needed?

Because specific gravity relates to density, knowing the SG of lead allows us to determine its density and thus calculate the exact mass of lead required to produce enough downward force to overcome the buoyant force on the wood.

If the wood's weight increases, does the minimum required mass of lead also increase?

Yes, increasing the weight of the wood increases the total downward force, so a larger mass of lead would be needed to sink the entire assembly.

Can the minimum mass of lead be determined without knowing the volume of the wood?

No, because the volume of the wood is essential to calculate the buoyant force and relate it to the weights involved. The specific gravity helps determine the volume from the mass, but explicit calculations require knowing or deriving the volume.

What assumptions are made when calculating the minimum mass of lead to sink the wood?

It is assumed that the system is in equilibrium (just sinking), the water is at standard conditions, the lead and wood are rigid and non-deformable, and there are no other forces (like drag or surface tension) significantly affecting the outcome.

Additional Resources

A 6.15-kg Piece Of Wood (SG = 0.50) Floats On Water: An In-Depth Analysis of Buoyancy, Material Properties, and the Minimum Mass of Lead Needed to Submerge

Floating objects have fascinated scientists and students alike, offering tangible insights into the principles of buoyancy and density. In this article, we explore the scenario of a 6.15-kg piece of wood with a specific gravity (SG) of 0.50 floating on water. We will analyze the physics behind why it floats, determine the minimum mass of lead required to submerge it, and discuss the broader implications of these calculations. This comprehensive review aims to clarify the concepts involved, present calculations step-by-step, and highlight key features, pros, and cons associated with such physical phenomena.

Understanding the Fundamentals: Buoyancy, Density, and Specific Gravity

Before delving into the problem specifics, it is essential to understand the fundamental concepts that govern buoyancy and material properties.

Buoyancy Force and Archimedes’ Principle

- Buoyancy Force: The upward force exerted by a fluid on an object submerged or floating within it.
- Archimedes’ Principle: The buoyant force on an object equals the weight of the displaced fluid.

Mathematically:

$$ F_b = \rho_{fluid} \times V_{displaced} \times g $$

Where:
- F_b = buoyant force
- ρ_{fluid} = density of the fluid (water in this case)
- $V_{displaced}$ = volume of fluid displaced
- g = acceleration due to gravity

Material Properties: Density and Specific Gravity

Understanding the material densities is crucial for analyzing buoyancy.

Specific Gravity (SG)

- Defined as the ratio of the density of a substance to the density of water at 4°C (which is approximately 1000 kg/m³).

$$
SG = \frac{\rho_{material}}{\rho_{water}}
$$

Given:
- SG of wood = 0.50
- SG of lead = 11.3

Calculations:

$$
\rho_{wood} = SG_{wood} \times \rho_{water} = 0.50 \times 1000\, \text{kg/m}^3 = 500\, \text{kg/m}^3
$$

\[

$$
\rho_{lead} = 11.3 \times 1000\, \text{kg/m}^3 = 11,300\, \text{kg/m}^3
$$

The significant difference in densities explains why wood floats and lead sinks.

Analyzing the Floating Wood: Calculating Displaced Volume

Given:
- Mass of wood $m_{wood} = 6.15\, \text{kg}$
- Density of wood $\rho_{wood} = 500\, \text{kg/m}^3$

The volume of the wood:

$$
V_{wood} = \frac{m_{wood}}{\rho_{wood}} = \frac{6.15}{500} = 0.0123\, \text{m}^3
$$

Since the wood floats, it displaces a volume of water equal to the volume of the submerged part of the wood, which creates a buoyant force balancing its weight.

Determining the Volume of Water Displaced When Floating

The weight of the water displaced must equal the weight of the wood:

$$
F_b = m_{water\,displaced} \times g
$$

But since $F_b = \text{Weight of displaced water}$:

$$
\rho_{water} \times V_{displaced} \times g = m_{wood} \times g
$$

Simplify:

$$
\rho_{water} \times V_{displaced} = m_{wood}
$$

Solve for $V_{displaced}$:

$$
V_{displaced} = \frac{m_{wood}}{\rho_{water}} = \frac{6.15}{1000} = 0.00615\, \text{m}^3
$$

This volume is less than the total volume of the wood (0.0123 m^3), indicating the wood is floating with part of it submerged.

Minimum Mass of Lead to Submerge the Wood

The core question: What is the minimum mass of lead hung from the wood to make it fully submerged? To achieve this, the combined weight (wood + lead) must be balanced by the buoyant force when the entire wood is submerged.

Condition for Full Submersion

When fully submerged:

$$
\text{Total weight} = \text{Buoyant force}
$$

$$
(m_{wood} + m_{lead}) \times g = \rho_{water} \times V_{total} \times g
$$

Where:
- $V_{total} = V_{wood} = 0.0123\, \text{m}^3$ (since the entire wood is submerged)

Solve for m_{lead}:

$$
m_{lead} = \rho_{water} \times V_{total} - m_{wood}
$$

Plugging in the numbers:

$$

$$
m_{lead} = 1000 \times 0.0123 - 6.15 = 12.3 - 6.15 = 6.15\, \text{kg}
$$

Thus, a minimum of 6.15 kg of lead must be hung from the wood to fully submerge it.

Implications of the Calculation and Physical Interpretation

This result has several interesting implications:

- The mass of lead needed equals the mass of the wood itself because the lead's density is extremely high, so a relatively small volume of lead would suffice if not constrained by the total mass needed.
- The total weight (wood + lead) becomes twice the weight of the wood alone, requiring the displaced water volume to support this increased weight.
- The full submersion occurs precisely when the combined weight equals the weight of the displaced water volume matching the entire volume of the wood.

Features, Pros, and Cons of Using Lead for Submersion

Features:

- High density allows small volume to produce significant weight.
- Useful in applications requiring precise ballast control.
- Relatively easy to shape and attach to objects.

Pros:

- Efficient in weight addition due to high density.
- Cost-effective compared to other dense materials.
- Readily available and malleable.

Cons:

- Toxicity poses environmental and health risks.
- Heavy and potentially hazardous to handle.
- Difficult to remove once attached, especially in submerged environments.

Broader Context and Practical Applications

Understanding how minimal masses of dense materials like lead can submerge objects has practical applications in:

- Ship ballast: Adjusting stability and buoyancy.
- Submarine design: Precise ballast control for diving and surfacing.
- Hydrodynamic experiments: Studying buoyant forces and fluid dynamics.
- Educational demonstrations: Visualizing principles of density and buoyancy.

Conclusion

The analysis of a 6.15-kg piece of wood with a specific gravity of 0.50 floating on water reveals the delicate balance between weight, volume, and buoyant forces. To fully submerge this piece of wood, a minimum of approximately 6.15 kg of lead must be hung from it—an interesting and practical illustration of how dense materials can dramatically influence buoyancy. This scenario underscores fundamental physics principles and highlights the importance of material properties in real-world applications. Whether for scientific, engineering, or educational purposes, understanding these concepts enhances our grasp of the natural laws governing floating and sinking phenomena.

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