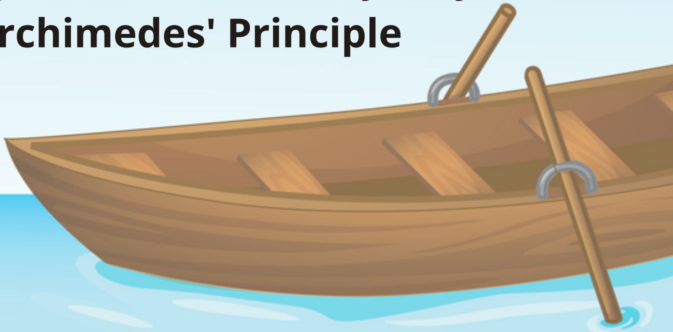
M.AFFENDI.B | SUZANA WATI A. | SITI HARNI.Z

THE FLOATING SECRETS

Unlocking the Power of Buoyancy and Archimedes' Principle



FIRST EDITION 2023

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Preface

Welcome to the fascinating world of buoyancy! In this book, we embark on a journey to explore the captivating principles and applications of buoyancy, a phenomenon that has intrigued scientists, engineers, and thinkers throughout history.

Buoyancy is not merely an abstract concept; it's a force of nature that plays a pivotal role in our everyday lives. From the graceful flight of hot air balloons to the majestic ships that navigate our oceans, buoyancy is an essential component of countless phenomena and technologies.

This book is designed to be a comprehensive guide to buoyancy. We will delve into the fundamental principles that govern buoyancy, unravel the mathematics behind it, and explore its diverse applications across various fields of science and engineering.

Our journey will take us from the ancient discoveries of Archimedes to the modern innovations that have harnessed the power of buoyancy to achieve remarkable feats. Along the way, we will encounter intriguing experiments, historical anecdotes, and practical insights that shed light on the profound influence of buoyancy on our world.

I hope this book inspires you to explore the depths of buoyancy, and to seek answers. Buoyancy is not only a force of nature; it's a force of inspiration, driving us to push the boundaries of what we know and what we can achieve.

Thank you for joining us in this buoyant journey.

Happy reading!

Meet Our Team!

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1 Introduction to Buoyancy - Setting the Stage

1.1 Archimedes Unveiled: Meet the legendary Archimedes

Archimedes, the legendary ancient Greek mathematician, physicist, engineer, and inventor, is widely regarded as one of the greatest scientists and thinkers of all time.

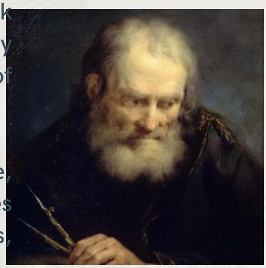


Figure 1: Archimedes.
(Source:
https://www.britannica.com/biography/Archimedes)

Around 287 BCE, Archimedes was born in Syracuse, Sicily, and is credited with making revolutionary advances in a number of disciplines, including mathematics, physics, and engineering.

His contributions made a significant contribution to the advancement of science and engineering, leaving a lasting legacy that still has an impact on knowledge and technology today.

Figure 2: Archimedes.
(Source:
https://www.britannica.com/biography/Archimedes)

1.1.1 Life and Background

Archimedes grew up in a prosperous family, and his education began in Alexandria, Egypt, a renowned center of learning during that era. He studied under the guidance of renowned scholars and mathematicians, which laid the foundation for his exceptional intellect and innovative thinking.

Archimedes returned to Syracuse, where he spent the majority of his life, conducting his research and contributing to the scientific community.

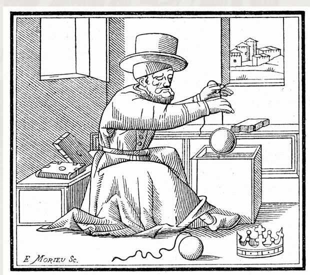


Figure 3: Archimedes.
(Source:
https://www.britannica.com/biography/Archimedes)

1.1.2 Archimedes' Principle

Archimedes' principle is one of his most celebrated contributions to physics and engineering. This principle states that when an object is submerged in a fluid, it experiences an upward buoyant force equal to the weight of the fluid displaced by the object.

Archimedes' principle provides a foundational understanding of buoyancy, explaining why certain objects float or sink in fluids and influencing the design of ships, submarines, and other floating structures.

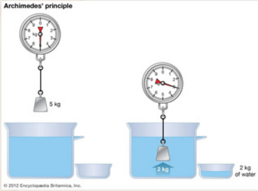


Figure 4: Archimedes' principle (Source: https://www.britannica.com/biography/Archimedes)

Fun Facts

Do You Know...??

What led to Archimedes discovering his principle?

King Heiron II of Syracuse (308 BC – 215 BC) had a pure gold crown made, but he thought that the crown maker might have tricked him and used some silver. Heiron asked Archimedes to figure out whether the crown was pure gold. Archimedes took one mass of gold and one of silver, both equal in weight to the crown. He filled a vessel to the brim with water, put the silver in, and found how much water the silver displaced. He refilled the vessel and put the gold in. The gold displaced less water than the silver. He then put the crown in and found that it displaced more water than the gold and so was mixed with silver. That Archimedes discovered his principle when he saw the water in his bathtub rise as he got in and that he rushed out naked shouting “Eureka!” (“I have found it!”) is believed to be a later embellishment to the story.

Activity 1

1. Experiment with different objects in water and observe their behavior. Ask yourself: Why do some objects float while others sink?
2. Build a boat using materials such as paper, plastic, or wood. Test its buoyancy by adding weight to it gradually and observing how it floats.
3. Make an object sink to the bottom of a pool, then try to make it rise to the surface again. Can you do this without touching the object?

1.2 Discovering the foundations of Archimedes' principle

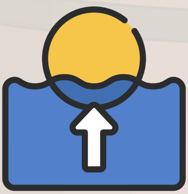
Discovering the basics of Archimedes' principle and understanding its meaning in terms of buoyancy is key to understanding the behavior of objects in liquids. Archimedes' principle, formulated by the ancient Greek scientist Archimedes, provides a fundamental understanding of the forces that act when an object is immersed in a liquid.

Basically, Archimedes' principle states that an object immersed in a liquid experiences an upward buoyant force equal to the mass of the liquid it displaces. In other words, the buoyant force on an object is proportional to the volume of liquid it displaces. This principle applies to both liquids and gases, which makes it possible to study the behavior of objects in different liquid environments.

The importance of Archimedes' principle lies in its ability to explain why certain objects float or sink in liquids. If the buoyant force acting on an object is greater than or equal to its weight, the object floats. On the other hand, if the buoyant force is less than its weight, the object sinks.

1.2.1 Understanding buoyancy

Understanding buoyancy is crucial in fields such as naval architecture, shipbuilding and engineering. For example, ship designers must consider Archimedes' principle to ensure that the ship displaces enough water to generate enough buoyancy to support its weight. By applying this principle, engineers can optimize the design of ships, submarines and other floating structures for stability and safety.



Archimedes' principle also has practical significance in everyday life. This explains why objects that are less dense than the fluid they are in, such as a ball floating in water, rise to the surface. On the other hand, objects denser than a liquid, such as a rock in water, sink.

In addition, Archimedes' principle provides a scientific basis for understanding the operation of various flotation devices such as life jackets and inflatable rafts. Using the principle of buoyancy, these devices are designed to displace enough fluid to support the weight of a person or object and keep them afloat.

1.3 The Enigma of Floating Objects

In the vast expanse of the natural world, few phenomena have captivated human imagination as much as the enigma of floating objects. From the tiniest leaf gently resting on the surface of a tranquil pond to the colossal ocean liners defying the depths of the sea, the dance of buoyancy has enthralled civilizations throughout history.

1.3.1 The Magic of Floating

We begin by delving into the everyday marvels that surround us, from the ethereal grace of soap bubbles ascending towards the heavens to the whimsical sight of a helium-filled balloon soaring through the sky. We unravel the scientific principles behind these enchanting phenomena, igniting a sense of wonder and curiosity in our readers. Through engaging anecdotes and captivating examples, we draw attention to the fundamental question: How do objects that are denser than the fluid they rest upon manage to stay afloat?

Activity 2

- Perform an experiment to demonstrate Archimedes principle.
- Fill a container with water, then add an object and measure the displacement of water.
- Calculate the weight of the displaced water and compare it to the weight of the object.
- Does the weight of the displaced water equal the weight of the object?

Activity 3

- Build a submarine using a water bottle, a balloon, and some tape.
- Fill the bottle with water, then inflate the balloon and attach it to the opening of the bottle. Release the submarine and observe how it behaves.

Activity 4

- Research the history of Archimedes and his contributions to science and mathematics. Write a report or give a presentation about his life and work.


"Give me a place to stand and
I will move the earth."
— Archimedes

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2

THE SCIENCE OF BUOYANCY

2 The Science Of Buoyancy

The science of buoyancy is a fascinating branch of physics that explores the behavior of objects immersed in fluids and the forces acting upon them. Let's delve deeper into the key principles and factors involved in the science of buoyancy:

Archimedes' Principle:

This principle states that when an object is submerged in a fluid, it experiences an upward buoyant force equal to the weight of the fluid it displaces. This buoyant force acts in the opposite direction to gravity, resulting in an apparent loss of weight of the object.

Density and Buoyancy:

Density is defined as the mass of an object divided by its volume. Objects with a lower density than the fluid in which they are submerged will experience a net upward force greater than their own weight, causing them to float. Conversely, objects with a higher density than the fluid will experience a net downward force, causing them to sink.

Determining Factors: Several factors determine the buoyancy of an object:

- Volume: The volume of the fluid displaced by the object plays a significant role in determining the magnitude of the buoyant force. The greater the volume of fluid displaced, the greater the buoyant force acting on the object.
- Mass: The mass of the object affects its overall weight. Objects with a greater mass experience a larger downward gravitational force, which needs to be balanced by an equally significant upward buoyant force for them to float.
- Fluid Density: The density of the fluid in which the object is submerged influences the buoyant force. Objects with a lower density than the fluid will have a greater buoyant force acting upon them.

Stable Equilibrium:

Objects that float in a fluid reach a state of stable equilibrium, where the buoyant force and the weight of the object are balanced. The object will float with a portion of its volume above the fluid's surface. The stability of an object in a fluid depends on its shape and distribution of mass. A lower center of mass and a wider base increase stability, while a higher center of mass and a narrow base may lead to instability and tipping.

Applications and Impact:

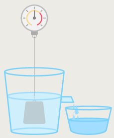
The science of buoyancy has numerous practical applications. It plays a vital role in shipbuilding, designing submarines, and determining the lifting capacity of hot air balloons. It also influences the behavior of objects submerged in liquids, such as the behavior of fish and other marine organisms in water.

CHAPTER TWO: THE SCIENCE OF BUOYANCY

2.1 Archimedes' Principle: The Foundation of Buoyancy

The science of buoyancy owes much of its development to Archimedes of Syracuse, an ancient Greek mathematician, physicist, and inventor. Archimedes' famous principle, discovered around 250 BC, forms the foundation of our understanding of buoyancy. This principle states that when a body is immersed in a fluid, it experiences an upward buoyant force equal to the weight of the fluid displaced by the body. In simpler terms, an object will float if it is less dense than the fluid it displaces and sink if it is denser.

The density of an object is determined by its mass and volume. If an object's density is less than that of the fluid it is placed in, it will experience a net upward force, causing it to float. Conversely, if its density is greater, it will sink. This principle is why heavy steel ships can float while lightweight wooden boats can also stay afloat.



2.2 Factors Affecting Buoyancy

Several factors affect the buoyant force experienced by an object:

- Density of the Object:

  An object's density, defined as its mass per unit volume, plays a significant role in determining whether it will float or sink. If the object's density is less than that of the fluid, it will experience a buoyant force greater than its weight and float. Conversely, if its density is greater, it will sink.

- Density of the Fluid:

  The density of the fluid in which an object is submerged is one of the most critical factors affecting buoyancy. Less dense fluids generate less buoyant force, while denser fluids generate more. For example, objects float more easily in freshwater than in denser fluids like seawater or brine.

- Volume of the Object:

  The volume of the object is directly proportional to the buoyant force it experiences. Objects with larger volumes displace more fluid and thus experience a stronger buoyant force. This is why increasing an object's size can make it more likely to float.

- Archimedes' Principle:

  Archimedes' principle states that the buoyant force on an object submerged in a fluid is equal to the weight of the fluid displaced by the object. This principle is fundamental in understanding buoyancy. It means that objects will displace their weight in fluid, resulting in an upward buoyant force equal to that weight.

- Shape and Design:

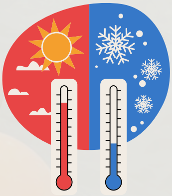
  The shape and design of an object can significantly impact its buoyancy. Objects with hollow structures or spaces filled with air or a less dense material can increase their overall volume while keeping their mass relatively low. This design helps maximize buoyancy, making them more likely to float.

- Gravity:

  The strength of gravity on a celestial body (e.g., Earth) directly influences the buoyant force experienced by an object. On a planet with a stronger gravitational field, objects must be less dense to float, while on a planet with weaker gravity, they can be denser and still float.

- Temperature and Pressure:

  Changes in temperature and pressure can affect the density of a fluid. For example, warm air is less dense than cold air, which is why hot air balloons rise. Similarly, variations in pressure in underwater environments can influence an object's buoyancy, especially in deep-sea applications.



- **Composition of the Fluid:**

  The composition of the fluid can affect buoyancy. For example, salty water is denser than freshwater, so objects will float more easily in freshwater. Additionally, the presence of dissolved gases, such as in the case of carbonated beverages, can alter the density of the fluid and impact buoyancy.

- **Buoyant Force Variation:**

  The buoyant force acting on an object can vary depending on its depth within a fluid. Deeper in the fluid, the pressure increases, and thus, the buoyant force also increases. This phenomenon can be seen in submarines, where ballast tanks are used to control depth by adjusting buoyancy.

In summary, buoyancy is influenced by a combination of factors, including the densities of both the object and the fluid, the volume of the object, the gravitational field strength, the shape and design of the object, and environmental factors like temperature and pressure. A comprehensive understanding of these factors is essential for engineers, scientists, and designers when working with buoyant forces in various applications.

2.3 Applications of Buoyancy

Buoyancy, the force that allows objects to float in a fluid medium, has a wide range of practical applications across various fields. Its fundamental principles have been harnessed to design and develop numerous technologies and innovations. Here are some of the key applications of buoyancy:

a) Ship Design and Navigation:

- Perhaps one of the most well-known applications of buoyancy is in ship design and navigation. Ships and boats are engineered to displace enough water to generate a buoyant force greater than their weight, allowing them to float. This principle enables the transportation of goods and people across oceans and waterways.

b) Submarines:

- Submarines are designed to control their buoyancy using ballast tanks. By adjusting the amount of water in these tanks, submarines can change their density and either float on the surface or dive to various depths underwater. Buoyancy control is essential for stealthy underwater operations and navigation.

c) Hot Air Balloons:

- Hot air balloons rely on the principle that hot air is less dense than the surrounding air. By heating the air inside the balloon, it becomes buoyant and rises. The control of this buoyancy allows hot air balloons to ascend and descend, providing a serene mode of aerial transportation and recreation.

d) Blimps and Airships:

- Similar to hot air balloons, blimps and airships use lighter-than-air gases, such as helium, to generate buoyant force. These aircraft are often used for advertising, surveillance, and certain cargo transport applications due to their ability to hover and maneuver.

e) Swimming and Diving Equipment:

- Buoyancy control is essential in swimming and diving. Devices like life vests, floatation devices, and buoyant wetsuits help individuals stay afloat and swim efficiently. Divers also use buoyancy compensators and weight belts to control their depth underwater.

f) **Oil and Gas Industry:**

- In offshore drilling operations, oil rigs and platforms must maintain buoyancy to remain stable on the water's surface. Buoyant structures are used to support drilling equipment, living quarters, and storage facilities for oil and gas production.

g) **Aquariums and Fish Farms:**

- Maintaining the buoyancy of aquatic habitats is crucial in aquariums and fish farms. Buoyant materials and structures, such as floating platforms, help create controlled environments for marine life and facilitate efficient breeding and cultivation practices.

h) **Underwater Archaeology and Salvage:**

- Buoyancy is essential in underwater archaeology and salvage operations. In these applications, equipment like buoyant lift bags and flotation devices are used to raise sunken objects or shipwrecks from the seabed.

i) **Space Exploration:**

- Spacecraft and space stations utilize buoyancy principles when in low Earth orbit. While not in a traditional fluid medium, these vehicles are in a state of continuous free fall, creating conditions analogous to buoyancy. Engineers use this knowledge to design and maneuver spacecraft.

j) **Floating Bridges and Floating Islands:**

- In some regions, engineers have developed floating bridges and floating islands to address transportation and living space challenges. These structures rely on buoyancy to stay afloat and provide stable platforms for various purposes.

k) **Buoyancy in Nature:**

- Buoyancy plays a vital role in the lives of aquatic animals, helping them control their depth in the water and conserve energy. Many marine creatures, such as fish and whales, adjust their buoyancy through specialized swim bladders or oil-filled tissues.

l) Agricultural Irrigation:

- Floating pumps and devices that use buoyancy are employed in agricultural irrigation systems to transport water across bodies of water, like rivers or reservoirs, to irrigate fields efficiently.

In conclusion, the applications of buoyancy are diverse and far-reaching, from the design of massive ocean liners to the exploration of outer space. This fundamental principle continues to inspire innovation and creativity across various industries, making it an essential concept in science and engineering.

"Eureka! Eureka! Supposed to have been his cry, jumping naked from his bath and running in the streets, excited by a discovery about water displacement to solve a problem about the purity of a gold crown."

~ Archimedes

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3 PRACTICAL APPLICATIONS

Experiment 1:

The Floating and Sinking Challenge

The "Floating and Sinking Challenge" is a classic and interactive experiment designed to help students grasp the fundamental principles of buoyancy. This experiment encourages students to predict whether various objects will float or sink in water and then test their predictions through observation and experimentation. It's an excellent way to introduce young learners to the concept of density and Archimedes' principle.

Materials Needed:

- A variety of objects with different shapes and sizes (e.g., wooden blocks, plastic toys, rubber balls, coins, aluminum foil, paper clips, etc.).
- A container of water (a clear container is ideal for better visibility)
- A notebook or worksheet for students to record their predictions and observations
- A marker for labeling objects

Steps:

1) Prediction:

Begin by discussing the concept of buoyancy and Archimedes' principle. Explain that whether an object floats or sinks in water depends on its density relative to the density of water.

2) Object Selection:

Have a selection of objects ready for students to examine. Ask each student or group of students to select an object from the collection.

3) Prediction:

Encourage students to predict whether their chosen object will float or sink in the water. Have them write down their predictions in their notebooks.

4) Testing:

One by one, place their selected objects into the container of water and observe what happens. Did the object float as predicted, or did it sink? Have students record their observations.

Discussion:

After each test, engage the class in a discussion. Ask students to share their observations and whether their predictions were correct. Encourage them to explain why each object floated or sank.

Density Discussion:

Emphasize that objects that are less dense than water float, while those denser than water sink. Discuss how the shape and volume of an object can influence its buoyancy.

Repeat:

Repeat the process with different objects, allowing students to make new predictions and observations.

Variations:

To add complexity, ask students to make hypotheses about what will happen if they alter the objects (e.g., folding a piece of paper into a different shape or attaching objects together). This encourages critical thinking and experimentation.

Key Takeaways:

The Floating and Sinking Challenge provides a hands-on and engaging way for students to explore the concept of buoyancy. It reinforces the idea that whether an object floats or sinks in a fluid depends on its density relative to the density of that fluid. Students learn to make predictions, record observations, and engage in discussions to understand why certain objects behave the way they do in water.

This experiment can be adapted for various grade levels, making it a versatile tool for teaching buoyancy concepts in science education.

By participating in the Floating and Sinking Challenge, students not only gain a practical understanding of buoyancy but also develop critical thinking skills and a curiosity about how the physical world operates.

Experiment 2:

Make a Tin Foil Boat: An Engaging Buoyancy Experiment

The "Make a Tin Foil Boat" experiment is a hands-on and engaging activity that allows students to explore the principles of buoyancy and Archimedes' principle through a fun and creative project. In this experiment, students are tasked with designing and constructing a boat using only aluminum foil, and then they test the boat's buoyancy by seeing how many marbles it can hold before sinking.

This experiment not only reinforces the concept of buoyancy but also encourages creativity and problem-solving skills.

Materials Needed:

- Sheets of aluminum foil (each student or group of students should receive one sheet)
- A container of water (a large plastic bin or a sink will work)
- Marbles or small weights (to test the boat's buoyancy)
- Optional: A ruler to measure the dimensions of the boat
- Optional: Markers or colored tape for decoration

Steps:

- Introduction:

Begin by introducing the concept of buoyancy and Archimedes' principle. Explain that the experiment involves designing a boat out of aluminum foil that can float on water while carrying marbles or small weights.

- Boat Design:

Give each student or group a sheet of aluminum foil and explain that they need to design a boat that can hold as many marbles as possible without sinking. They can fold, shape, and mold the foil in any way they like to create their boats.

CHAPTER 3: PRACTICAL APPLICATIONS

- Construction:

Students start building their foil boats. Encourage them to think about the shape, size, and structure of the boat. Discuss how the boat's design may affect its buoyancy.

- Testing: Once the boats are constructed, fill the container with water. Have students gently place their boats in the water one by one, ensuring they don't get wet in the process.

- Adding Marbles: Students take turns adding marbles (or small weights) one by one into their boats. They should count how many marbles their boats can hold before they start to sink.

- Observations and Data: As students conduct their experiments, they should record their observations and data, including the boat's design, the number of marbles it held, and any observations about how the boat behaved as it carried the marbles.

Discussion:

After all boats have been tested, gather the students to discuss their findings. Encourage them to share their boat designs and the strategies they used to make their boats more buoyant.

Key Takeaways:

- The "Make a Tin Foil Boat" experiment is a hands-on way to explore the principles of buoyancy and Archimedes' principle while encouraging creativity and problem-solving skills.
- Students learn that the shape and design of an object can influence its buoyancy.
- The experiment reinforces the idea that an object can float when its buoyant force (due to displacement of water) is greater than or equal to its weight.
- This engaging and interactive experiment not only reinforces scientific concepts but also provides a memorable and enjoyable learning experience. It allows students to apply their understanding of buoyancy in a practical context and fosters a sense of curiosity about the physical world.

Experiment 3:

Density Tower Experiment: A Visual Exploration of Density and Buoyancy

The Density Tower experiment is a captivating and visually engaging activity that demonstrates the concepts of density, buoyancy, and Archimedes' principle. It involves creating a layered tower of liquids with different densities, such as water, oil, and syrup, to observe how objects sink or float in each layer. This experiment provides a clear illustration of how objects behave in fluids with varying densities and reinforces the principle that buoyancy is determined by the relative density of an object and the surrounding fluid.

Materials Needed:

- A tall, transparent container (a clear glass or plastic cylinder is ideal)
- Liquids with different densities, such as:
  - Water
  - Vegetable oil
  - Corn syrup or honey
  - Dishwashing liquid
  - Rubbing alcohol
- Small objects with varying densities (e.g., plastic beads, small pieces of fruit, coins)
- Optional: Food coloring for visual contrast
- A dropper or pipette for adding liquids

Steps:

1.Introduction:

Begin by explaining the concept of density to the participants. Emphasize that density is a measure of how much mass is packed into a given volume and that objects with greater density than a fluid will sink, while those with lower density will float.

2. Layering the Liquids:

In the transparent container, start by carefully pouring the densest liquid at the bottom (e.g., corn syrup or honey). Use a dropper or pipette to add each liquid layer slowly, one on top of the other, in the following order (from bottom to top):

- Corn syrup or honey
- Dishwashing liquid
- Water (with a different color, if desired)
- Vegetable oil
- Rubbing alcohol

3. Observations:

As you pour each liquid layer, observe how they stack on top of each other without mixing due to their differing densities. The liquids should form distinct layers in the container, with the densest at the bottom and the least dense at the top.

4. Testing Objects:

Invite participants to drop various small objects into the density tower and observe how they behave. Some objects may float in one layer but sink when they reach a layer with a higher density. Encourage participants to make predictions about which objects will float or sink in each layer.

5. Discussion:

Facilitate a discussion about the results. Ask participants to explain their observations and whether their predictions were accurate. Discuss how the concept of density relates to the behavior of objects in the density tower.

Key Takeaways:

- The Density Tower experiment provides a visual and hands-on demonstration of how density affects the buoyancy of objects in different fluids.
- It reinforces the idea that objects with higher density than the surrounding fluid will sink, while those with lower density will float.
- The experiment highlights the practical applications of density and buoyancy principles in various real-world scenarios.

The Density Tower experiment is not only educational but also captivating due to its colorful and visually appealing results. It serves as an effective tool for teaching the concepts of density and buoyancy while sparking curiosity and engagement among participants.

Experiment 4:

Hot Air Balloon Simulation: Illustrating Buoyancy and Density

The Hot Air Balloon Simulation is an educational and interactive experiment that simulates the principles behind hot air balloons, providing students with a hands-on opportunity to explore the concepts of buoyancy and the relationship between density and buoyancy.

Materials Needed:

- A small, empty, and lightweight plastic or paper bag (representing the balloon)
- A hairdryer or heat gun with a low-speed setting
- String or twine
- A source of electricity for the hairdryer
- A safe and open workspace

Steps:

1.Introduction to Buoyancy and Density:

- Begin by introducing students to the concepts of buoyancy and density. Explain that buoyancy is the force that makes objects float in a fluid (liquid or gas) and that it depends on the relative densities of the object and the surrounding fluid.

2. Setting Up the Balloon:

- Attach a length of string or twine to the top of the plastic or paper bag, creating a makeshift hot air balloon. Ensure that the string is long enough to allow the balloon to rise without interference.

3. Cold Air Test:

- Start the experiment with the plastic or paper bag in its normal state, representing cold air. Hold the bag by the string and ask students to predict what will happen when the bag is released. Have them record their predictions.

4. Heating the Air:

- Turn on the hairdryer or heat gun to its lowest speed setting and direct the hot air into the open mouth of the bag. Allow the bag to inflate with the hot air. Explain that heating the air inside the bag reduces its density, making it lighter than the surrounding cold air.

5. Balloon Ascent:

- Once the bag is sufficiently inflated with hot air, release it while still holding onto the string. Students will observe that the balloon rises into the air, defying gravity. This ascent occurs because the hot air inside the balloon is less dense than the surrounding cooler air, resulting in a net upward buoyant force.

6.Discussion and Analysis:

- After the balloon has risen, gather the students to discuss their observations and compare them to their initial predictions.
- Emphasize the role of density in the balloon's rise and how the decrease in air density due to heating creates buoyant force.
- Relate the simulation to real hot air balloons, explaining that they operate on the same principles.

Key Takeaways:

- The Hot Air Balloon Simulation provides a tangible and memorable demonstration of buoyancy and the relationship between density and buoyancy.
- Heating the air inside the balloon decreases its density, making it less dense than the surrounding air and causing the balloon to rise.
- This experiment connects abstract scientific principles to a real-world application, illustrating how understanding buoyancy and density has led to the invention and operation of hot air balloons.
- The Hot Air Balloon Simulation not only reinforces the fundamental concepts of buoyancy and density but also engages students by allowing them to witness the principles in action. It encourages curiosity and critical thinking while demonstrating the practical applications of scientific knowledge.

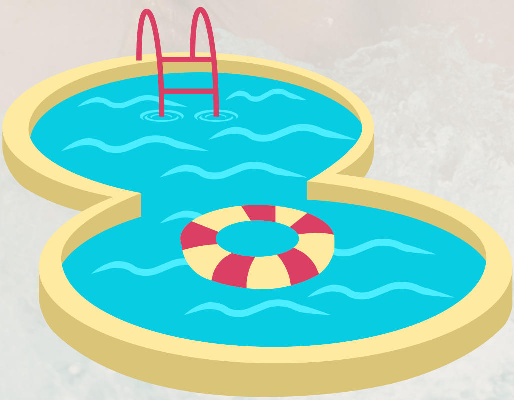
4 BUOYANCY IN EVERYDAY LIFE

4 BUOYANCY IN EVERYDAY LIFE

Buoyancy is a fundamental principle of fluid mechanics that affects numerous aspects of our daily lives, often without us realizing it. It's the force that allows objects to float in a fluid, whether it's a solid object in a liquid or a gas bubble in a liquid or another fluid.

A. SWIMMING AND FLOATING IN WATER:

- Explanation: When you're in a swimming pool or any body of water, you experience buoyancy. It happens because the human body, with its density being slightly less than that of water, displaces an amount of water equal to its weight. According to Archimedes' principle, there's an upward buoyant force acting on you that counteracts gravity.
- Practical Use: Buoyancy allows us to enjoy swimming and water sports comfortably. It also plays a crucial role in designing life jackets and flotation devices, which keep us afloat when needed.



B. HOT AIR BALLOONS:

- **Explanation:**

Hot air balloons work on the principle of buoyancy. When the air inside the balloon is heated, it becomes less dense than the surrounding air. This lower density creates an upward buoyant force that lifts the balloon.

- **Practical Use:** Hot air balloons offer a unique and serene way to travel through the air. They rely on buoyancy to carry passengers safely above the ground.

C. HYDROSTATIC PRESSURE:

- **Explanation:**

Buoyancy is also at play in hydrostatic pressure, which is why you feel more pressure on your body when you dive deep into a pool. The pressure increases with depth because the water exerts a force upward on your body due to buoyancy.

- **Practical Use:**

Understanding hydrostatic pressure is crucial in scuba diving and engineering applications like designing submarines and underwater structures.

D. BAKING AND COOKING:

Buoyancy affects the way food cooks. For instance, when you're boiling pasta, the noodles are denser than boiling water initially. As they absorb water and become less dense, they rise to the surface, indicating that they are cooked.

Buoyancy helps us gauge the readiness of food without using timers. It's a practical application in everyday cooking.

Scenario: Cooking Pasta

- Buoyancy Principle:

When you cook pasta, the noodles are less dense than water. As they absorb water and become less dense, they float to the surface, indicating their readiness.

- Application:

Observing the buoyant behavior of pasta while cooking helps determine its doneness without needing a timer. This practical use of buoyancy ensures perfectly cooked pasta every time.

E. GAS BALLOONS (HELIUM BALLOONS):

Scenario: Buoyant Forces in Balloons

Balloons filled with helium float in the air because helium is less dense than the surrounding air, creating an upward buoyant force.

- Application:

Helium-filled balloons used in celebrations and events showcase buoyancy in action. These balloons rise due to the buoyant force, adding a sense of festivity and fun to the occasion.

F. AIRPLANES AND FLIGHT:

- Explanation: While not as apparent, the principle of buoyancy also applies to flight. Aircraft generate lift due to their wing design, which creates an upward buoyant force that counteracts gravity and allows them to stay airborne.

- Practical Use: This is critical for air travel, allowing us to reach distant destinations quickly and efficiently.

Scenario: Passenger Buoyancy in Aircraft

- Buoyancy Principle: Buoyancy helps explain why heavy airplanes can fly. The shape of the aircraft's wings generates lift, which opposes gravity and keeps the plane airborne.

- Application: When an airplane takes off, the shape of its wings and the speed at which it moves through the air generate sufficient lift to counteract the force of gravity. Passengers experience the effects of this buoyant force, as they feel lighter during flight.

SCAN ME

Newtons laws and buoyancy explain how airplanes fly
@Landell, N

(PDF) Newton explains lift. Buoyancy explains flight.

PDF | A re-evaluation of the existing evidence engenders an improved...

researchgate.net

SUMMARY

In summary, buoyancy is a fundamental principle of physics that influences various aspects of our daily lives. Understanding how it works helps us design vehicles, enjoy recreational activities, and even cook our meals more effectively. It's a concept that highlights the fascinating interplay between physics and everyday experiences.

Case Study: The Tragedy of the Sewol Ferry and Buoyancy

Introduction:

The sinking of the Sewol ferry in South Korea on April 16, 2014, was a devastating maritime tragedy that claimed the lives of 304 people, mostly high school students. This case study examines the events leading to the sinking of the Sewol ferry from the perspective of buoyancy and its implications on the safety and rescue efforts.

Understanding Buoyancy and its Role:

Buoyancy plays a crucial role in the design and stability of ships and boats. When a vessel is in water, it experiences an upward force called buoyant force, which is equal to the weight of the water displaced by the submerged portion of the vessel.

If the buoyant force is greater than or equal to the weight of the vessel, it will float. However, if the weight of the vessel exceeds the buoyant force, it will sink.

The Sewol Ferry Tragedy:

On the fateful day of April 16, 2014, the Sewol ferry departed from Incheon, South Korea, with 476 passengers, mostly students from Danwon High School.

The ferry encountered trouble when it made a sharp turn while sailing in the waters off the southwestern coast of South Korea. Due to the shift in weight caused by the sharp turn, the ferry listed heavily to one side, compromising its stability.

Contributing Factors:

1. Overloading:

One of the major factors contributing to the tragedy was the overloading of the Sewol ferry. The ferry was carrying significantly more cargo and passengers than its designed capacity. This increased the weight and affected its buoyancy, making it more susceptible to instability.

2. Improper Ballast:

Proper ballasting is crucial for maintaining a ship's stability. Ballast tanks, usually located in the lower parts of the vessel, are used to adjust the weight and balance. In the case of the Sewol ferry, it was reported that the ballast tanks were not adequately filled, which further compromised its stability.

3. Insufficient Stability Assessment:

The stability assessment of the Sewol ferry, including calculating the center of gravity, weight distribution, and load limits, was not conducted meticulously. This lack of thorough evaluation and adherence to safety regulations contributed to the tragedy.

4. Delayed Evacuation and Rescue Efforts:

As the ferry listed and began sinking, the response and evacuation efforts were delayed, hindering the timely rescue of the passengers. The inadequate training of the crew and lack of emergency preparedness further exacerbated the situation.

Case Study: Titanic - A Case Study in Buoyancy

1.Introduction:

The sinking of the RMS Titanic on April 15, 1912, is one of the most famous maritime disasters in history. Beyond the tragic loss of life, the Titanic serves as a compelling case study in the principles of buoyancy, offering valuable lessons in ship design, stability, and the application of Archimedes' principle.

2. Buoyancy Principles:

Buoyancy is the force that allows objects to float in a fluid, such as water. It is governed by Archimedes' principle, which states that the buoyant force acting on an object immersed in a fluid is equal to the weight of the fluid displaced by the object.

In the case of the Titanic, understanding buoyancy is crucial to comprehend the sequence of events that led to its sinking.

3. The Titanic's Buoyancy Design:

The Titanic was an engineering marvel of its time, designed to provide both luxury and safety. Its construction involved the use of a series of watertight compartments, which were intended to make the ship virtually unsinkable. These compartments could be sealed off independently to prevent water from flooding the ship.

However, the Titanic's buoyancy was compromised by several factors:

- Compartmentalization: While the Titanic had 16 watertight compartments, they were not designed to be completely watertight. The walls dividing the compartments extended only a few feet above the waterline, allowing water to spill over the top in the event of a breach in multiple compartments.

- Insufficient Lifeboats: The ship carried far fewer lifeboats than needed for its full complement of passengers and crew, which affected its overall buoyancy. Inadequate lifeboats contributed to the high loss of life during the disaster.

- Lack of Bulkhead Extension: The watertight bulkheads did not extend all the way to the top of the ship's hull, allowing water to flow from one compartment to another once the lower compartments began flooding.

4. Sequence of Events:

- Collision with the Iceberg: The Titanic struck an iceberg on the night of April 14, 1912. The iceberg punctured the ship's hull, creating multiple breaches in the lower compartments.

- Compartment Flooding: Water rapidly filled the breached compartments, causing the ship to start tilting forward and to the right due to the uneven flooding.

- Loss of Buoyancy: As more compartments filled with water, the ship's buoyancy was compromised. The combined weight of the water in the breached compartments exceeded the buoyant force acting on the ship, causing it to sink.

- Insufficient Lifeboats: With the ship sinking quickly, there were not enough lifeboats to accommodate all the passengers and crew, resulting in a tragic loss of life.

5. Lessons Learned :

The Titanic disaster led to a significant reassessment of ship design, safety regulations, and emergency procedures. New guidelines were established to ensure an adequate number of lifeboats for all passengers and crew, and modern ships incorporate advanced technologies for monitoring buoyancy and stability.

Additionally, the disaster emphasized the importance of training crew members in emergency protocols.

CHAPTER 4: BUOYANCY IN EVERYDAY LIFE

6. Conclusion:

The Titanic tragedy serves as a stark reminder of the critical role of buoyancy in ship design and maritime safety. While the Titanic was touted as "unsinkable," its design flaws and inadequate safety measures, such as the limited number of lifeboats, ultimately led to its demise. Understanding the principles of buoyancy and addressing design deficiencies are essential lessons learned from this historic maritime disaster.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FLOATING SECRETS

Unlocking the Power of Buoyancy and Archimedes' Principle

1ST EDITION 2023

5

THE MATH BEHIND BUOYANCY

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 1

Calculate both the volume of the stone and its specific gravity, provided that it registers a weight of 500 N in the atmosphere and 250 N when submerged in water.

Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 2

A stone weight was 600 N in air, the same stone weight 250 N in water. Calculate the stone volume and relative density.

Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 3

Determine both the volume and relative density of an object using its weight in the air, which amounts to 2800 N, and its weight when submerged in water, which is 1800 N.

Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 4

Compute the specific gravity of a concrete block given its weight of 54.5 kg in the air and 35 kg when submerged in water.

Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 5

Find the volume, density, and specific gravity of an object, noting that it registers a weight of 3.5 N when submerged in water and 5 N when submerged in an oil with a specific gravity of 0.75
(Answer: $6.17 \times 10^{-4} m^3$, $1578.286 kg/m^3$, 1.6)

Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 6

Calculate the weight of an object in air and determine its specific gravity, knowing that it measures 2.5 m x 1.5 m x 2.0 m and weighs 3 kN when submerged in water.

Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 7

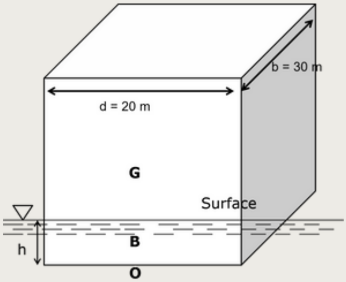
Calculate the volume, specific gravity, and weight of an object in the air, given that it weighs 1000 N when submerged in water and 1300 N when submerged in oil with a specific gravity of 0.8.

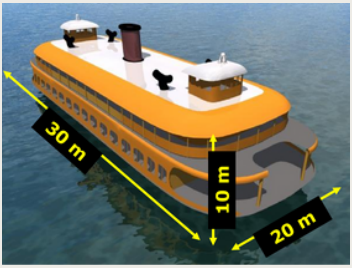
Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 8

Find the metacentric height of a ferry navigating the Strait of Tebrau, given a water density of 1200 kgm-3. The ferry has dimensions of 30 meters in length, 20 meters in width, and 10 meters in height, with a total mass of 600 metric tons.





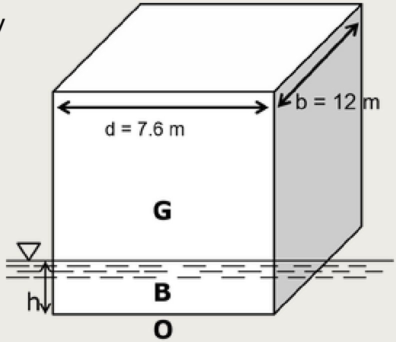
Note :
h = depth of immersed

Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 9

Calculate the metacentric height of a ferry with a weight of 95 metric tons floating in seawater with a density of 1026 kg/m^3. The ferry has dimensions of 15 meters in length, 8 meters in width, and 3 meters in height

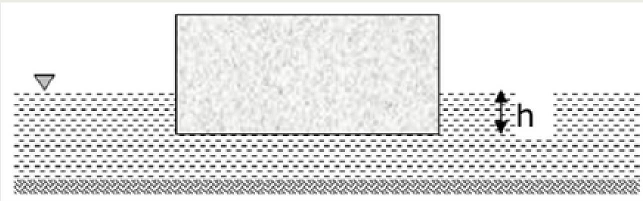


Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 10

Calculate the value of "h" for a wooden block measuring 0.6 meters in length, 0.5 meters in width, and 0.3 meters in height, which is floating in water with a relative density of 0.60. (Answer: 5.56 m)

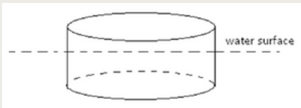


Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 11

Determine the metacentric height and identify the type of equilibrium for a cylinder with a diameter of 3 meters, a height of 2 meters, and a mass of 1200 kg, while it is floating in water. (Answer: 0.663 m, stable equilibrium)



Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 12

Calculate the mass of the wood, its density, and the metacentric height, given that a piece of wood measuring 60 cm in length, 40 cm in width, and 20 cm in height is floating in water with 20 percent of its volume above the water surface, and it is in stable equilibrium.
(Result: Wood mass = 12 kg, wood density = $800 kgm^{-3}$, GM = 0.084 m)

Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 13

A ship with a mass of 3000 metric tons is floating on the sea (1025 kgm-3). The ship discharges 100 metric tons of ballast water, causing it to become immersed to a depth of 6.4 meters. Subsequently, the ship cruises along a river. Calculate the depth to which the ship is immersed in the river.
(Result: 6.56 m)

Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 14

Determine the depth to which a wooden cube measuring 0.6 meters on each side is immersed in water, with the wood density 600kgm-3. (Result: 0.3 m)

Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 15

Calculate the depth to which a pontoon, weighing 60 metric tons and measuring 6 meters in width, 15 meters in length, and 2.4 meters in height, becomes immersed when loaded with 120×10^3 kg of gravel stones, while it is floating in seawater with an density 1025 kgm^{-3}.
(Result: 1.95 m)

Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 16

Calculate the weight of the empty rectangular pontoon and the weight of the agriculture crop being transported through a river. The pontoon has dimensions of 8.0 meters in width and 26 meters in length. When empty, it has a depth of immersion of 1.5 meters, and when loaded with the crop, it has a depth of immersion of 2.1 meters.

Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 17

Calculate the value of "h," representing the height, for an object measuring 0.4 meters in length, 0.2 meters in width, and an unknown height "h," while it is floating in water. The mass of the object is 12 kilograms.

<u>Calculation & Answer</u>

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 18

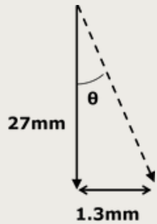
Determine the depth, denoted as "h," to which a cuboid-shaped wooden object with dimensions of 0.4 meters in width, 0.6 meters in length, and 1 meter in height becomes immersed in water. The relative density of the wood is 0.65.
(Result: 0.65 m)

Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 19

Calculate the metacentric height of a pontoon by considering that a weight of 20 kN is moved horizontally for a distance of 9 meters on the pontoon deck. The pontoon has a displacement of 1500 kN in water, and this movement creates a 27 mm long pendulum that moves horizontally by 1.3 mm.



(Result= 2.5m)

Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 20

Calculate the metacentric height of a vessel with dimensions of 60 meters in length, 8.4 meters in width, and a displacement of 15 MN. When a weight of 150 kN is moved horizontally for a distance of 6 meters across the deck, it causes the ship to heel through 3 degree. (Ans; 1.15m)

Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 21

Determine the metacentric height of a ship, which has a weight of 20 MN, and experiences a heel of 2 degrees when a load of 150 kN is shifted across its deck over a distance of 5 meters.
(Result = 1.07m)

Calculation & Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

QUESTION 22

Calculate the metacentric height of a ship weighing 32 MN. When a load of 200 kN is shifted across the deck over a distance of 6 meters, it induces a horizontal movement of 75 mm in a 3-meter-long pendulum.

(Result: 1.5m)

Calculation & Answer


Answer

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q1)

Calculate both the volume of the stone and its specific gravity, provided that it registers a weight of 500 N in the atmosphere and 250 N when submerged in water.

Solution:

Weight of stone in air = 500 N
Weight of stone in water = 250 N

The net value of the buoyancy,

R = Weight of stone in air - weight of stone in water

R = 500−250 = 250 N
R = ρgV

V = R/ρg
= 250/1000 × 9.81
= 0.025 m^3

Mass of stone $= \frac{weight of stone in air}{g} = \frac{500}{9.81} = 50.968 kg$

Density of stone $= \frac{mass of stone}{volume} = \frac{50.968}{0.025} = 2038.72 \frac{kg}{m^3}$

Specific gravity of stone

$$= \frac{density of stone}{density of water} = \frac{2038.72}{1000} = 2.039$$

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q2)

A stone weight was 600 N in air, the same stone weight 250 N in water. Calculate the stone volume and relative density.

(Result: $0.036m^3$ **, 1.699)**

Solution:

R = 600−250 = 350 N
R = ρgV

$$V = \frac{R}{\rho g} = \frac{350}{1000 \times 9.81} = 0.036m^3$$

$$Mass of stone = \frac{weight of stone in air}{g} = \frac{600}{9.81} = 61.162kg$$

$$Density of stone = \frac{mass of stone}{volume} = \frac{61.162}{0.036} = 1698.944\frac{kg}{m^3}$$

$$Specific Gravity of Stone = \frac{density of stone}{Density of water} = \frac{1698.944}{1000} = 1.699$$

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q3)

Determine both the volume and relative density of an object using its weight in the air, which amounts to 2800 N, and its weight when submerged in water, which is 1800 N.

(Result: $0.102m^3$ **, 2.8)**

Solution:

R = 2800−1800 = 1000 N

R = ρgV

$$V = \frac{R}{\rho g} = \frac{1000}{1000 \times 9.81} = 0.102m^3$$

$$Mass of object = \frac{weight of object in air}{g} = \frac{2800}{9.81} = 285.423kg$$

$$Density of object = \frac{mass of object}{volume of object} = \frac{285.423}{0.102} = 2798.265\frac{kg}{m^3}$$

$$Specific gravity of stone = \frac{density of object}{density of water} = \frac{2798.265}{1000} = 2.8$$

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q4)

Compute the specific gravity of a concrete block given its weight of 54.5 kg in the air and 35 kg when submerged in water.
(Result: 2.868)

Solution:

$$Weight of water displaced = 54.5 - 35 = 19.5 kg$$

$$\rho = \frac{m}{V}$$

$$V = \frac{m}{\rho} = \frac{19.5}{1000} = 0.019 m^3$$

$$Density of block = \frac{mass of block in air}{volume of block} = \frac{54.5}{0.019} = 2868.42 \frac{kg}{m^3}$$

$$Specific Gravity of block = \frac{Density of block}{Density of water} = \frac{2868.42}{1000} = 2.868$$

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q5)

Find the volume, density, and specific gravity of an object, noting that it registers a weight of 3.5 N when submerged in water and 5 N when submerged in an oil with a specific gravity of 0.75
(Result: $6.17 \times 10^{-4} m^3$**,** $1578.286 kg/m^3$**, 1.6)**

Solution:

$$W_{object} = W_{displacedwater}$$

$$W_{objectinair} - W_{objectinwater} = \rho g V_{object}$$

$$W_{object} - 3.5 = 1000 \times 9.81 \times V_{object}$$

$$W_{object} = 9810 \times V_{object} + 3.5 \qquad \text{(equation 1)}$$

$$W_{objectinair} = V_{objectinoil} = \rho g V_{oil}$$

$$W_{object} - 5 = (0.75 \times 1000) \times 9.81 \times V_{object}$$

$$W_{object} - 5 = 7357.5 \times V_{object} \qquad \text{(equation 2)}$$

Substitute (equation 1) in (equation 2),

$$(9810 V_{object} + 3.5) - 5 = 7357.5 V_{object}$$

$$2452.5 V_{object} = 1.5$$

$$V_{object} = \frac{1.5}{2452.5}$$

$$V_{object} = 0.000617 m^3$$

Substitute $V_{object} = 0.000617 m^3$ **in (equation 1),**

$$W_{object} = (9810 \times 0.000617) + 3.5 = 9.553 N$$

$$\omega = \frac{W}{V} = \frac{9.553}{0.000617} = 15482.982 \frac{N}{m^3}$$

$$\rho = \frac{\omega}{g} = \frac{15482.982}{9.81} = 1578.286 \frac{kg}{m^3}$$

$$\gamma = \frac{Densityofobject}{Densityofwater} = \frac{1578.286}{1000} = 1.578$$

SOLUTION (Q6)

Calculate the weight of an object in air and determine its specific gravity, knowing that it measures 2.5 m x 1.5 m x 2.0 m and weighs 3 kN when submerged in water.

(Result: 31.43kN, 1.067)

Solution:

$$W_{objectinair} - W_{objectinwater} = \rho g V_{object}$$

$$W_{object} - 3 = 9.81 \times (2.5 \times 1.5 \times 2.0)$$

$$W_{object} = 73.575 + 3$$

$$W_{objectinair} = 76.575$$

$$\omega = \rho g$$

$$m = \frac{W}{g} = \frac{76575}{9.81} = 7805.810kg$$

$$\rho = \frac{m}{V} = \frac{7805.810}{3} = 1067.96\frac{kg}{m^3}$$

$$\gamma = \frac{Densityofobject}{Densityofwater} = \frac{1067.96}{1000} = 1.068$$

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q7)

Calculate the volume, specific gravity, and weight of an object in the air, given that it weighs 1000 N when submerged in water and 1300 N when submerged in oil with a specific gravity of 0.8.

(Result: $0.306m^3$, 3901.86 N, 1.3)

Solution:

$$W_{objectinair} - W_{objectinwater} = \rho g V_{object}$$

$$W_{object} - 1000 = 1000 \times 9.81 \times V_{object}$$

$$W_{object} = 9810 \times V_{object} + 1000$$

(equation 1)

$$W_{objectinair} - W_{objectinoil} = \rho g V_{object}$$

$$W_{object} - 1300 = (0.8 \times 1000) \times 9.81 \times V_{object}$$

$$W_{object} - 1300 = 7848 V_{object}$$

(equation 2)

Substitute (equation 1) in (equation 2),

$$(9810 V_{object} + 1000) - 1300 = 7848 V_{object}$$

$$1962 V_{object} = 300$$

$$V_{object} = \frac{300}{1962}$$

$$V_{object} = 0.153m^3$$

Substitute $V_{object} = 0.153m^3$ **in equation 1**

$$W_{object} = 9810 \times V_{object} + 1000$$

$$W_{object} = (9810 \times 0.153) + 1000 = 2500.93N$$

$$\omega = \frac{W}{V} = \frac{2500.93}{0.153} = 16345.948Nm^{-3}$$

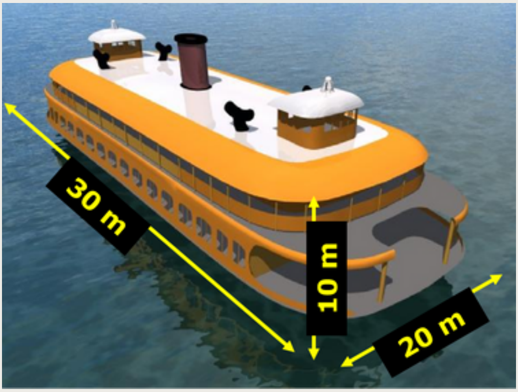
$$\rho = \frac{\omega}{g} = \frac{16345.948}{9.81} = 1666.254kgm^{-3}$$

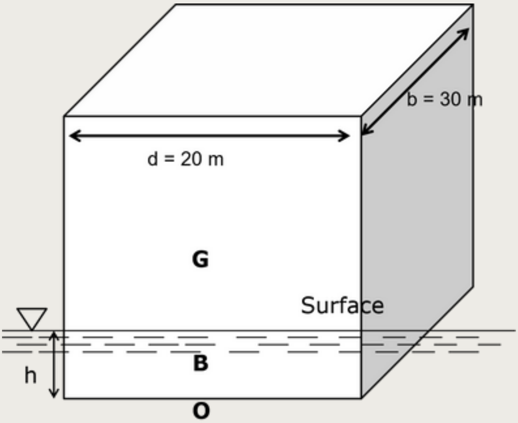
$$\gamma = \frac{densityofobject}{densityofwater} = \frac{1666.254}{1000} = 1.67$$

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q8)

Find the metacentric height of a ferry navigating the Strait of Tebrau, given a water density of 1200 kgm-3. The ferry has dimensions of 30 meters in length, 20 meters in width, and 10 meters in height, with a total mass of 600 metric tons.





Note :
h = depth of immersed

CHAPTER 5: THE MATH BEHIND BUOYANCY

Solution:

$$W_{ferry} = W_{displacedwater}$$

$$W_{ferry} = mg = (600 \times 1000) \times 9.81 = 5.886 \times 10^6 N$$

$$W_{displacedwater} = \rho g V = 1200 \times 9.81 \times (30 \times 20 \times h) = 7.0632 \times 10^6 h$$

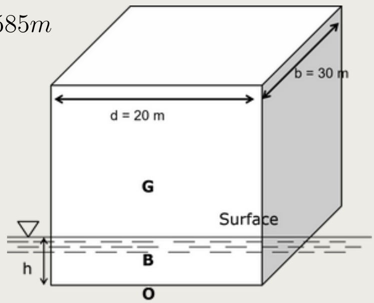
$$W_{ferry} = W_{displacedwater}$$

$$5.866 \times 10^6 = 7.0632 \times 10^6 h$$

$$h = \frac{5.866 \times 10^6}{7.0632 \times 10^6}$$

h = 0.831 m

$$BG = OG - OB = \frac{10}{2} - \frac{0.831}{2} = 4.585m$$



$$I = \frac{bd^3}{12} = \frac{30 \times 20^3}{12} = 20000m^4$$

$$V = 30 \times 20 \times 0.831 = 498.6m^3$$

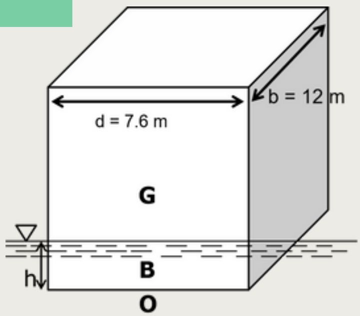
$$MB = \frac{I}{V} = \frac{20000}{498.6} = 40.112m$$

$$GM = MB - BG = 40.112 - 4.585 = 35.53m$$

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q9)

Calculate the metacentric height of a ferry with a weight of 95 metric tons floating in seawater with a density of 1026 kg/m^3. The ferry has dimensions of 15 meters in length, 8 meters in width, and 3 meters in height.



Solution:

$$W_{ferry} = W_{displacedwater}$$

$$W_{ferry} = mg = (95 \times 1000) \times 9.81 = 931950N$$

$$W_{displacedwater} = \rho g V = 1026 \times 9.81 \times (15 \times 8 \times h)$$
$$= 12077807.2h$$

$$W_{ferry} = W_{displacedwater}$$

$$931950 = 12077807.2h$$

$$h = \frac{931950}{1207807.2}$$

$$h = 0.772m$$

$$BG = OG - OB = \frac{3}{2} - \frac{0.722}{2}$$

$$BG = 1.114m$$

$$I = \frac{b \times h^3}{12} = \frac{15 \times 8^3}{12} = 640m^4$$

$$V = 15 \times 8 \times 0.772 = 92.64m^3$$

$$MB = \frac{I}{V} = \frac{640}{92.64} = 6.908m$$

$$GM = MB - BG = 6.908 - 1.114 = 5.794m$$

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q10)

Calculate the value of "h" for a wooden block measuring 0.6 meters in length, 0.5 meters in width, and 0.3 meters in height, which is floating in water with a relative density of 0.60.

(Result: 5.56 m)

Solution:

$$V_{block} = 0.6 \times 0.5 \times 0.3 = 0.09m^3$$
$$m_{block} = \rho V = (0.6 \times 1000) \times 0.09 = 54kg$$
$$W_{ferry} = mg = 54 \times 9.81 = 529.74N$$

$$\begin{aligned} W_{displacedwater} &= \rho g V \\ &= 1000 \times 9.81 \times (0.6 \times 0.5 \times h) \\ &= 2943h \end{aligned}$$

$$W_{ferry} = W_{displacedwater}$$

$$529.74 = 2943h$$

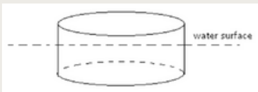
$$h = \frac{529.74}{2943}$$

$$h = 0.18m$$

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q11)

Determine the metacentric height and identify the type of equilibrium for a cylinder with a diameter of 3 meters, a height of 2 meters, and a mass of 1200 kg, while it is floating in water.
(Result: 0.663 m, stable equilibrium)



Solution

$$W_{ferry} = mg = 1200 \times 9.81 = 11772N$$

$$W_{displacedwater} = \rho g V$$

$$= 1000 \times 9.81 \times \left(\frac{\pi \times 2^2}{4} \times h\right)$$

$$= 30819h$$

$$W_{ferry} = W_{displacedwater}$$

$$11772 = 30819h$$

$$h = \frac{11772}{30819}$$

$$h = 0.382m$$

$$BG = OG - OB = \frac{2}{2} - \frac{0.382}{2}$$

$$= 0.809m$$

$$I = \frac{\pi \times 3^4}{64} = 3.977m^4$$

$$V = \frac{\pi \times 3^2}{4} \times 0.382 = 2.701m^3$$

$$MB = \frac{I}{V} = \frac{3.977}{2.701} = 1.472m$$

$$GM = MB - BG = 1.472 - 0.809 = 0.663m$$

GM is positive. $\therefore$ Stable equilibrium

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q12)

Calculate the mass of the wood, its density, and the metacentric height, given that a piece of wood measuring 60 cm in length, 40 cm in width, and 20 cm in height is floating in water with 20 percent of its volume above the water surface, and it is in stable equilibrium.
(Result: Wood mass = 12 kg, wood density = $800kgm^{-3}$, GM = 0.084 m)

Solution

$$V_{wood} = 0.6 \times 0.4 \times 0.2 = 0.048m^3$$

$$V_{waterdisplaced} = \frac{80}{100} \times 0.048 = 0.038m^3$$

$$W_{wood} = W_{waterdisplaced}$$

$$= 1000 \times 9.81 \times 0.038 \ = 372.78N$$

$$W_{wood} = mg$$

$$m_{wood} = \frac{W_{wood}}{g} \quad = \frac{372.78}{9.81} \quad = 38kg$$

$$\rho_{wood} = \frac{m_{wood}}{V_{wood}} \quad = \frac{38}{0.048} \quad = 791.667kgm^{-3}$$

$$BG = OG - OB$$

$$= \frac{1}{2} - \frac{0.8}{2} = 0.01m$$

$$I = \frac{b \times d^3}{12}$$

$$I = \frac{0.5 \times 0.3^3}{12} = 1.125 \times 10^{-3}m^4$$

$$MB = \frac{I}{V} = \frac{1.125 \times 10^{-3}}{0.012} \quad = 0.09375m$$

$$GM = MB - BG = 0.09375m - 0.01m$$

$$= 0.084m$$

SOLUTION (Q13)

A ship with a mass of 3000 metric tons is floating on the sea (1025 kgm-3). The ship discharges 100 metric tons of ballast water, causing it to become immersed to a depth of 6.4 meters. Subsequently, the ship cruises along a river. Calculate the depth to which the ship is immersed in the river.

(Result: d = 6.56 m)

Solution

$$W_{ship} = W_{waterdisplacedonsea} = W_{waterdisplacedonriver}$$

$$\rho g V_{sea} = \rho g V_{river}$$
$$(1025 \times 9.81 \times A \times 6.4) = (1000 \times 9.81 \times A \times d)$$
$$d = 6.56m$$

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q14)

Determine the depth to which a wooden cube measuring 0.6 meters on each side is immersed in water, with the wood density 600kgm-3.

Solution

$$V_{wood} = 0.6 \times 0.6 \times 0.6 = 0.216m^3$$

$$\rho_{wood} = \frac{m}{V}$$

$$m_{wood} = \rho_{wood} \times V_{wood} \quad = 600 \times 0.216 = 129.6kg$$

$$W_{wood} = 129.6kg \times 9.81 = 1271.376N$$

$$W_{wood} = W_{displacedwater}$$

$$1271.376 = \rho g V_{displacedwater}$$

$$1271.376 = 1000 \times 9.81 \times (0.6 \times 0.6 \times h)$$

$$h = 2.778m$$

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q15)

Calculate the depth to which a pontoon, weighing 60 metric tons and measuring 6 meters in width, 15 meters in length, and 2.4 meters in height, becomes immersed when loaded with 120 x 10^3 kg of gravel stones, while it is floating in seawater with an density 1025 kgm-3.

(Result: h = 1.95 m)

Solution

$$W_{pontoon} + W_{gravelstone} = [(60 \times 1000) + (120 \times 1000)] \times 9.81$$

$$W_{pontoon} + W_{gravelstone} = 1765800N$$

$$W_{pontoon} + W_{gravelstone} = W_{waterdisplaced}$$

$$1765800 = 1025 \times 9.81 \times (6 \times 15 \times h)$$

$$h = \frac{1765800}{904972.5}$$

$$h = 1.95m$$

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q16)

Calculate the weight of the empty rectangular pontoon and the weight of the agriculture crop being transported through a river. The pontoon has dimensions of 8.0 meters in width and 26 meters in length. When empty, it has a depth of immersion of 1.5 meters, and when loaded with the crop, it has a depth of immersion of 2.1 meters.

Solution

$$W_{pontoon} = W_{waterdisplaced}$$
$$W_{pontoon} = \rho g V$$
$$W_{pontoon} = 1000 \times 9.81 \times (8.0 \times 26 \times 1.5)$$
$$= 3060720N$$
$$W_{pontoonloaded} = W_{waterdisplaced}$$
$$W_{pontoonloaded} = \rho g V_{waterdisplaced}$$
$$W_{pontoonloaded} = 1000 \times 9.81 \times (8.0 \times 26 \times 2.1)$$
$$= 4285008N$$
$$W_{crop} = W_{pontoonloaded} - W_{pontoon}$$
$$W_{crop} = 4285008 - 3060720N = 1224288N$$

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q17)

Calculate the value of "h," representing the height, for an object measuring 0.4 meters in length, 0.2 meters in width, and an unknown height "h," while it is floating in water. The mass of the object is 12 kilograms.

(Result: 0.15m)

Solution

$$W_{object} = 12 \times 9.81 = 117.72N$$

$$W_{object} = W_{displacedwater}$$

$$117.72 = \rho g V_{displacedwater}$$

$$117.72 = 1000 \times 9.81 \times (0.4 \times 0.2 \times h)$$

$$h = 0.15m$$

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q18)

Determine the depth, denoted as "h," to which a cuboid-shaped wooden object with dimensions of 0.4 meters in width, 0.6 meters in length, and 1 meter in height becomes immersed in water. The relative density of the wood is 0.65.

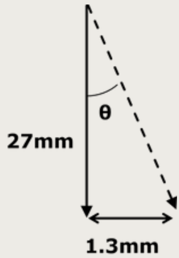
Solution

$$
\begin{aligned}
V_{wood} &= 0.4 \times 0.6 \times 1 = 0.24 m_3 \\
\rho_{wood} &= \frac{m}{V} \\
m_{wood} &= \rho_{wood} \times V_{wood} = 650 \times 0.24 = 156kg \\
W_{wood} &= 156 \times 9.81 = 1530.36N \\
W_{wood} &= W_{displacedwater} \\
1530.36 &= \rho g V_{displacedwater} \\
1530.36 &= 1000 \times 9.81 \times (0.4 \times 0.6 \times h) \\
h &= 0.65m
\end{aligned}
$$

SOLUTION (Q19)

Calculate the metacentric height of a pontoon by considering that a weight of 20 kN is moved horizontally for a distance of 9 meters on the pontoon deck. The pontoon has a displacement of 1500 kN in water, and this movement creates a 27 mm long pendulum that moves horizontally by 1.3 mm.

(Result= 2.5m)



Solution

Given:

w = 20 kN; x = 9m and W = 1500kN

We know that the angle of heel,

$$tan\theta = \frac{1.3}{27} = 0.048$$

$$GM = \frac{w \cdot x}{W tan\theta}$$

$$GM = \frac{20 \times 9}{1500 \times 0.048} = 2.5m$$

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q20)

Calculate the metacentric height of a vessel with dimensions of 60 meters in length, 8.4 meters in width, and a displacement of 15 MN. When a weight of 150 kN is moved horizontally for a distance of 6 meters across the deck, it causes the ship to heel through 3 degree.

(Result: 1.15m)

Solution

Given:

w = 150 000 N; x = 6m and W = 15 000 000 N

We know that the angle of heel, $\theta = 3^{\circ}$

$$tan3^{\circ} = 0.0524$$

$$GM = \frac{w \cdot x}{W tan\theta}$$

$$= \frac{150000 \times 6}{15000000 \times 0.0524} = 1.145m$$

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q21)

Determine the metacentric height of a ship, which has a weight of 20 MN, and experiences a heel of 2 degrees when a load of 150 kN is shifted across its deck over a distance of 5 meters.

(Result = 1.07m)

Solution

Given:

w = 150 000 N; x = 5m and W = 20 000 000 N

We know that the angle of heel, $\theta = 2^{\circ}$

$$tan 2^{\circ} = 0.0349$$

$$GM = \frac{w \cdot x}{W tan\theta}$$

$$= \frac{150000 \times 5}{20000000 \times 0.0349} = 1.074m$$

CHAPTER 5: THE MATH BEHIND BUOYANCY

SOLUTION (Q22)

Calculate the metacentric height of a ship weighing 32 MN. When a load of 200 kN is shifted across the deck over a distance of 6 meters, it induces a horizontal movement of 75 mm in a 3-meter-long pendulum.

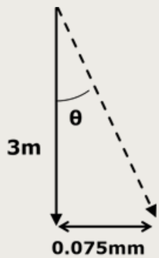
(Result: 1.5m)

Solution

Given:

w = 200 000 N; x = 6m and W = 32 000 000 N

We know that the angle of heel,



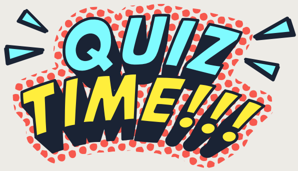
$$tan\theta = \frac{0.075}{3} = 0.025$$

$$GM = \frac{w \cdot x}{W tan\theta}$$

$$GM = \frac{20000 \times 6}{32000000 \times 0.025} = 1.5m$$


QUIZ TIME!!!

CHAPTER 5: THE MATH BEHIND BUOYANCY



QUESTION 1

Determine the metacentric height of a ship with a weight of 32 MN. When a 200 kN load is shifted 6 meters across the deck, it results in a horizontal displacement of a 3 meter long pendulum by 75 mm.

10 marks

QUESTION 2

Calculate the metacentric height of a vessel with dimensions of 60 meters in length, 8.4 meters in width, and a displacement of 15 MN. When a weight of 150 kN is moved horizontally for a distance of 6 meters across the deck, it results in a heel angle is 3 degrees.

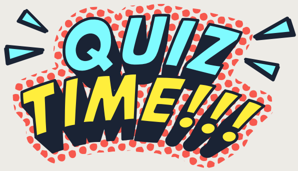
10 marks

QUESTION 3

Determine the specific gravity of a concrete block, given its weight of 64.5 kg in the air and 45 kg when submerged in water.

5 marks

CHAPTER 5: THE MATH BEHIND BUOYANCY



QUESTION 4

A ship weighs 32MN. If a load of 200kN is moved through a distance of 6m across the deck, it cause 3m long pendulum to move 75mm horizontally. Find the metacentric height of the ship.

10 marks

QUESTION 5

A vessel has a length of 60m, width 8.4m and a displacement 15MN. A weight of 150kN moved through a distance of 6m across the deck causes the ship to heel through 3°. Determine the metacentric height.

10 marks

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