Archimedes' Principle

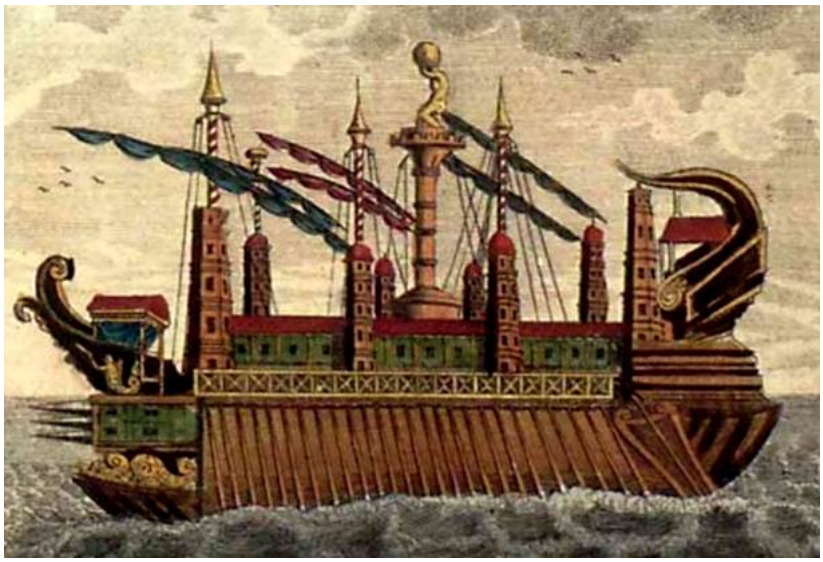
Learning Objectives

- Finding out the parameters which affect buoyant force
- Understanding of Archimedes' Principle.

Minimum Time Required: 2 sessions of 40 min each

Type of Learning Unit: Laboratory and classroom

Links to Curriculum: NCERT Class 9th Science chapter 10



Artist, U. (2015, November 13). Syracusia. Ancient History Encyclopedia. Retrieved from https://www.ancient.eu/image/4170/

Syracusia

A long time ago, around 3rd century BC, in Syracuse, Italy, lived Archimedes, an engineer, physicist, inventor and astronomer. He is well known as one of the most influential thinkers of his era. In popular stories, he is famous for supposedly coining the term 'Eureka' that he shouted as he ran naked on the streets of Syracuse on discovering the principles of buoyancy.

As the story goes, King Hiero of Syracuse wanted to build the largest ship of his time as a gift to Egypt's ruler Ptolemy. This ship would be 50 times bigger than the largest ancient warships and could be considered as the 'Titanic' of its time.

But, could a ship of this size float ? It was like asking, "can a mountain fly ?". King Hieron called Archimedes to solve the problem, who wondered about it for days. He got tense as the days passed by. One day, wondering about the problem, tensed, he decided to take a bath. He laid down in the bathtub and after some thought he realized a solution to the problem and in amazement and joy he ran out of the bathtub naked onto the streets of Syracuse, shouting Eureka! , Eureka!

What did he discover in the bathtub ?

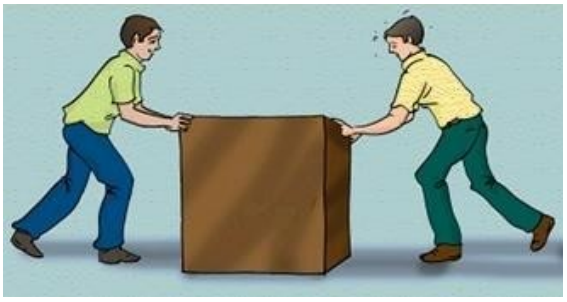
To answer this question we look into the phenomena of buoyancy, of how objects float or sink. We will go through some experiments to see what properties of an object affect the buoyancy of objects and Archimedes' thought process to answer these questions.

Introduction

Have you ever jumped into a pond, well or a pool of water ? If you have, you would have experienced a strange thing that happens. When you are in the water, you feel lighter compared to when you are standing outside. Besides, when you try to push down any floating object (Tennis ball, empty water bottle) in a vessel filled with water, you feel the object pushing your hand up and on removing the hand, the object rises up to the surface of the water.

WHAT IS THAT UPWARD FORCE

We know that, if an object at rest is pulled or pushed in opposite directions with two equal forces, the object does not move. In this case, we say forces are balancing each other.
Some such scenarios are : two persons pushing a table in the opposite direction such that the table remains at rest or in a tug of war when two different groups pull the rope in opposite directions but the knot remains at rest in the original position.



Borrowed from NCERT, class 8, Science textbook.

1. What must be the forces acting on an object when it floats on water ? you can explain with the help of a diagram.

we know that the weight of the object always acts in the downward direction. So, when an object floats in water there must be an upward force acting on the object that balances the weight of the object and prevents it from sinking. This upward force is also called as upthrust or buoyant force.

Question:
Which properties of the object/fluid decide how large/small would be the upward force ?

Let the students come up with their own ideas of what properties would affect the upward force.
1) Volume of object submerged
2) Weight of the object
3) Shape of object
4) Nature of the material (metal, plastic, wood)
5) Volume of fluid
6) nature of the fluid (pain water, salt water, oil)

Let us explore these questions and try to do some experiments to understand why objects float.

Materials

For Task 1 and 2: (i) Bucket/beaker half filled with water, (ii) Spring balance (iii) objects with the same volume but different weights (v)Salt (v) Digital weighing machine
For Task 3: i) A strong wooden stick, (ii) bucket filled with water, (iii) thread, (iv) wax candle, (v) match box and (vi) 2 stones of unequal (but nearly equal) masses

Task 1 : Does the upthrust depend upon the weight of the object ?

As discussed earlier, you would know the interesting thing that a small stone immediately sinks whereas a large ship floats on water.

Question: This raises a question, whether the upward force on an object depends upon the weight of the object ? What do you think?

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Collect objects that have the same volume but different weights and submerge them in water one by one measuring the upward force on them. You can do this with the help of a spring balance. Collect containers of the same size, add playing marbles/small stones/mud/clay etc to these containers in different amounts, so that each container has different weight. Remember, you should add sufficient playing marbles/small stones/mud/clay to each container so that it completely sinks in water. Note down the readings of the upward force for each of the containers.

What do you observe ?

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What you conclude from this observation?

Allow students to elicit and discuss their ideas and help them to understand that when the object is in water the buoyant force acts on it in the upward direction and balances a part of the weight of the object and thus, we see a reduced reading for the weight of the object in the spring balance. So, the difference in the two readings should give us the upward force acting on the object.
We use this experimental idea to check on what properties of the body and the fluid does this upward force depend upon.

Task 2 : Does the upthrust depend upon the nature of the fluid ?

Do you know that scuba divers carry more weight on them when they dive in salt water compared to when they dive in freshwater. Why do scuba divers care about the salinity of water?

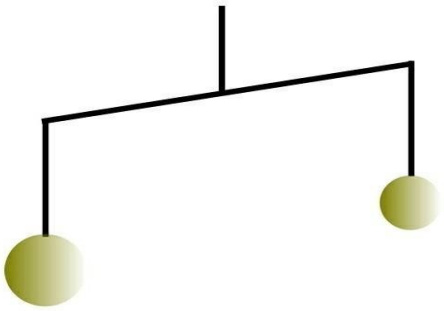
Gibb, Natalie. (2019, August 22). Buoyancy in Salt Water vs Fresh Water. Retrieved from https://www.liveabout.com/buoyancy-salt-water-vs-fresh-water-2962936

Let's try to find out. Use three different fluids like saltwater, water, oil and fully submerge the same object in these different fluids to measure the upward force acting on the object

What do you observe ?

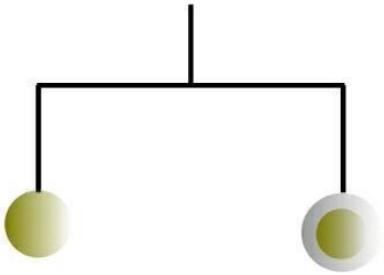
The difference in density between water and saltwater is very small, so in order to effectively see the effect of the density of the fluid on upward force, it is better to use objects with a greater volume so that greater amount of fluid is displaced and the small density difference can make an impact on the upward force that can be measured.

Task 3 : Does the upthrust depend upon the volume of the object ?

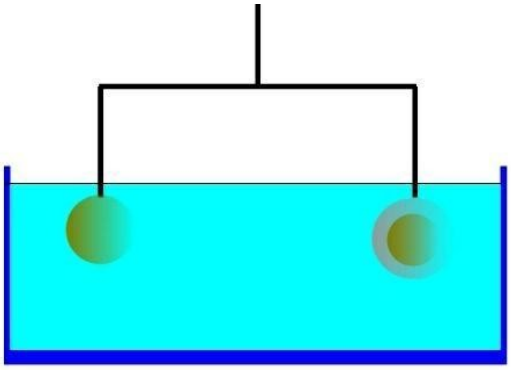


Stick and stone assembly as common balance

Make a structure similar to a common balance using a stick, thread and 2 stones (slightly unequal masses). Tie the stones by threads at equal distance from the centre at either ends of the stick (figure above). Since, mass of the stones are unequal, the stick will not remain horizontal. Drop molten wax on the stone of lower mass stone until the stick becomes horizontal (Figure a) below.



(a) Stick and stone assembly with wax coating on the lighter stoner



(b) Stones immerse in water

Question: Suppose the above balance is immersed in a bucket filled with water (Figure b) above. Predict the orientation of the balance. Will it remain horizontal?

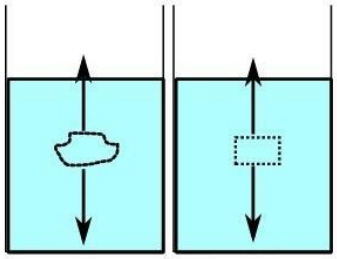
Now immerse the balance in a bucket and observe (Figure b) above. What do you observe ? Is it consistent with your prediction?

What can we conclude from this experiment ?

Task 4: A thought experiment: Quantifying the upward force

Summarize your observations In the previous tasks.

Suppose you have a beaker filled with water. Consider an imaginary block of water of any shape in this beaker . Now, as the water in the beaker is still, this block of water is stationary. What are the forces acting on the imaginary block of water ? Can you come up with an expression for the upward force?

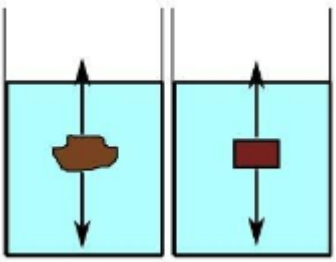


The downward force on the block of water which is due to its weight is balanced by an upward force which has to be equal to its weight.

Thus, Upward force on the imaginary block of water is equal to the weight of the block of water.

Now, imagine that you replace this imaginary block of water by an identical block of same shape and size but of different material.

How much is the upward force acting on this object ?



Is this consistent with your earlier observations ?

The upward force is always applied by the water on the object. As our replacement does not change the orientation of the surrounding water. Thus, the upward force on the object is equal to the weight of the block of water that it displaces. In other words, the upward force acting on the object is equal to the weight of the fluid it displaces.

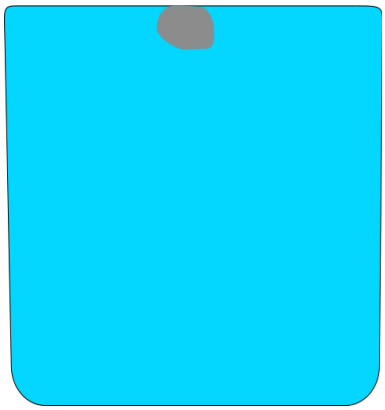


Figure A

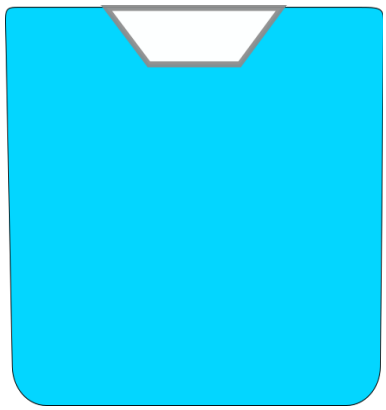


Figure B

Imagine, we take a solid piece of metal and put it in a beaker filled with water (Figure A), we know that this piece of metal will sink down to the bottom of the beaker. Why does this happen ? Explain this in terms of the force acting on a piece of metal.

Now, we take an object made of the same metal and having the same weight but in the shape of a boat as shown in (Figure B) above.
What are the forces acting on this object ? In comparison to the earlier piece of metal which force acting on the object has changed ?
Discuss and explain various scenarios that can happen.
Discuss and explain the conditions under which the object will float or sink.

Can you think of a way to actually do this experiment ?

Now, we fill this object completely with water (Figure C). Can you say for sure that that this object will sink or float ? Discuss and explain your answers.

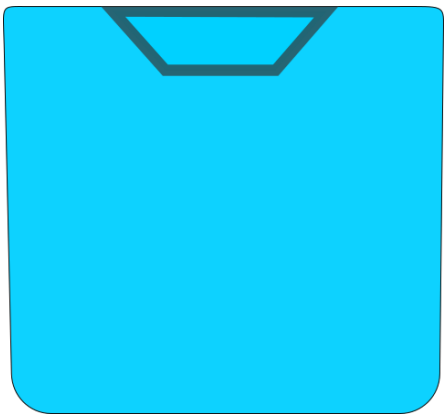
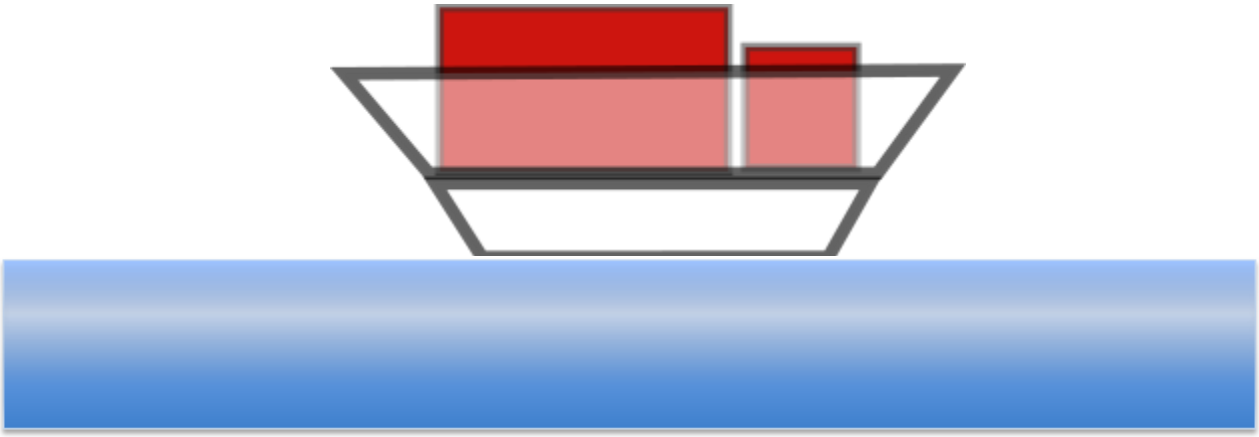


Figure C

Can you think of a way to do this experiment ?

To try out this experiment, take a bunch of nails and tie them with a rubber band, weigh the nails and find a metal tiffin box of the same weight. This can be used to replicate above experiment.



The above image is a simple model for the ship of Syracuse that we talked about at the beginning of the lesson. The part of the ship that touches the water is called the underside of the ship. Now if you have to build a large ship that can carry a huge load, how should the underside of the ship be designed ?

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References

Artist, U. (2015, November 13). Syracusia. Ancient History Encyclopedia. Retrieved from https://www.ancient.eu/image/4170/

Gibb, Natalie. (2019, August 22). Buoyancy in Salt Water vs Fresh Water. Retrieved from https://www.liveabout.com/buoyancy-salt-water-vs-fresh-water-2962936