AP Physics – Buoyancy

Buoyancy

How do massively heavy humungous ships float? An aircraft carrier weighs almost a ***hundred thousand tons***. So why doesn't it sink like a stone?

Aristotle thought it was due to the shape of a body. If the body had sharp edges, it would sink. If the body was smooth and rounded – like the hull of a ship – it would float. (So why do you have all those round rocks on the bottom of a river?)

Like most of the teachings of Aristotle, this is pure nonsense. The guy who actually figured out why things float was another Greek genius, ________________________ (*ca*. 287 – 212 B.C.). He discovered how ***buoyancy*** works. Buoyancy is an ______________________________ that a ________________________ on an object that is ____. It causes things to float or if it sinks it results in an apparent loss of weight of the object. This is called the ________________________________.

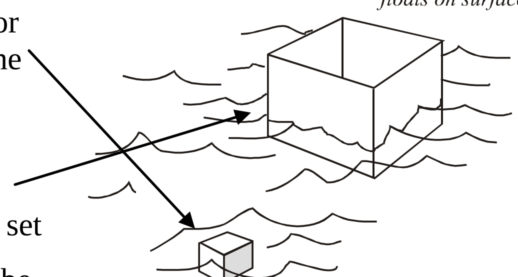
The important physics law dealing with buoyancy is called Archimedes' Principle.

Archimedes' Principle ≡ An object is buoyed up by a force ________________ to the __________________ of the ___________________ it __________________________.

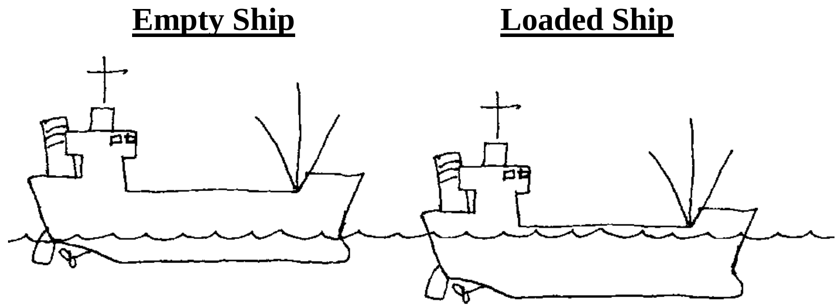
This rule is true both for ______________ and _______________________, since they are both fluids.

Archimedes' lost principle ≡ When a body is immersed in water, the phone rings :)

Floating and Sinking: You have 2 tons of steel. Steel is 9 times denser than water, so the 2 tons of steel will only displace about 2/9 or 0.22 tons of water. The buoyant force is not nearly enough to float the block, so it will sink.



We now take the same 2 tons of steel and make a box from it. This hollow box has a much greater volume than did the cube. When you set the box in the water, it displaces a larger volume of water than the cube did, it is the displaced volume of fluid which creates the buoyant force. As the box sinks deeper into the water, it displaces more and more water, which causes the buoyant force to increase. When the buoyant _________________ is _________________ to the ____________________ of the box, it ___________________________________ and floats. The ___________________ of the box is __________________ to the _______________________________ so the _________ force on the system is ___________. So if the box is big enough, it will float.



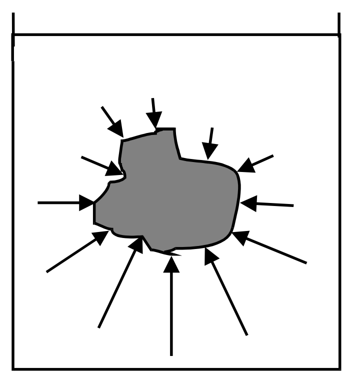
As cargo ships are loaded with freight, they sink deeper into the water. As they sink deeper, they displace more water. This increases the buoyant force. The boat’s weight and the buoyant force are at equilibrium. The upward buoyant force is equal to the weight of the ship. As long as the total weight of the ship does not exceed the weight of the water displaced, the ship will float.

Buoyancy In Air: Air is a fluid and Archimedes' principle applies to it just as it does to liquids.

> ***An object surrounded by air is buoyed up by a force equal to the weight of the air displaced.***

_______________________ and blimps ___________________________________ just as boats float on water. A cubic meter of air has a mass of around 1.2 kg, so its weight is around 12 N. Thus any object that has a volume of one cubic meter and a weight less than 12 N would float, i.e., rise. If it weighs more than 12 N, it would sink, i.e., fall.

Cause of the Buoyant Force: You toss a rock into the water and it sinks. The forces exerted by the pressure of the water act perpendicularly to the outer surfaces of the rock (Pascal’s principle).



The ____________________________________ pushing in on the sides

___________________ each other out.

This does _____________________________ with the ______________________

forces. As the _____________________________________, the pressure increases.

This means that the ______________________ pushing ______, _______ the

________________________ of the rock, are ________________________________

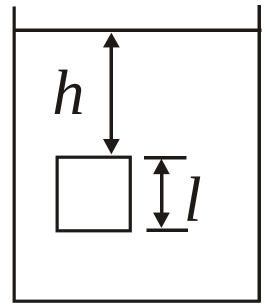
the _______________________ pushing _______________ on the top of the rock.

This is because the bottom of the rock is at a greater depth than the top of the rock, so the pressure is greater.

Recall that $P = \rho g h$, so the greater the depth the greater the pressure. The difference in the forces on the top and bottom are responsible for the buoyant force.

Finding the Buoyant Force: A cube with area ***A*** on all its sides is immersed in a fluid.

We can find the force pushing down on the top. We can also find the force pushing up on the bottom surface of the cube:



$$P = \frac{F}{A} \quad \text{so} \quad F = PA$$

We also know that $P = \rho g h$

We can plug that into the force equation we just developed:

Force on top: $F_{Top} = P_{Top}A \quad = \rho g h A$

Force on Bottom: $F_{Bot} = P_{Bot}A \quad = \rho g (h + l) A$

g is the acceleration of gravity. ***l*** is the length of each side of the cube. ***h*** is the depth of the top of the cube.

The force on the bottom is greater than the force on top, the difference is the buoyant force. We can find this difference:

$$\Delta F = F_{Bot} - F_{Top} = \rho g (h + l) A - \rho g h A$$

$$\Delta F = \rho g A\left((h + l) - h\right) \quad = \rho g A l$$

The area of the cube ***A*** multiplied by length of the cube's side ***l*** is the volume of the cube, so:

$$\Delta F = \rho V g$$

But the difference in the force on the top and bottom, ***ΔF***, is the buoyant force. Let's call it F_B.

$$F_{buoy} = \rho V g$$ ***Buoyant force equation***

F_{Buoy} is the buoyant force, ***ρ*** is the ____, ***g*** is the acceleration of gravity, and ***V*** is the volume of fluid that is displaced.

This is the exact same equation we worked out to find the weight of an object using density and volume. All we're really doing is finding the weight of the fluid that was displaced.

Apparent Weight: If the object's __________________ is ______________ than the ________________ force, the object will ________________. If the object's ___________________ is ______________________ than the ______________________ force, the object will __________, but it will weigh less. We call this the apparent weight, $\boldsymbol{F_A}$. The apparent weight is simply the difference between its actual weight and the buoyant force.

$$F_A = w - F_B$$ ***This is basically the NET force on the object***

Practice Problem:

A cube of steel that measures 5.0 cm on each side is immersed in water. The density of steel is 9.0 x 10^3 kg/m^3. The density of water is 1.0 x 10^3 kg/m^3. What is the (a) buoyant force acting on the cube and what is (b) its apparent weight?

(a) Find the buoyant force.

The volume of the cube is:

(b) Find the apparent weight.

To find the weight of the cube use:

Now we can plug and chug:

To find the apparent weight we use this equation:

Practice Problem:

A cork has a volume of 4.25 cm^3. The density of cork is 207 kg/m^3. (a) What volume of the cork is beneath the surface when the cork floats in water? (b) What downward force is needed to completely submerge the cork?

(a) The floating cork will displace a volume of water equal to its own weight. We can use the density of the cork to find its weight. With the weight, we can then calculate the volume of water displaced.

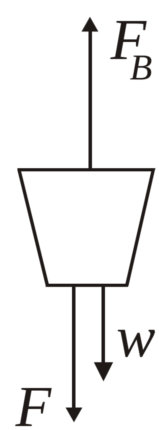
Be sure to convert the volume of the cork to cubic meters:

Now we find the weight of the cork:

Now we can find the volume of water this represents. We set the buoyant force equal to this value:

In centimeter it would be:

(b) To find the force needed to sink the cork, we have to analyze the forces. First we will draw a FBD:



The forces are: $\boldsymbol{F_B}$ the upward buoyant force, ***w*** the downward weight of the cork, and ***F*** is the force we must push down with to make it sink.

The sum of the forces must be zero:

$$F_B - F - w = 0 \qquad F = F_B - w$$

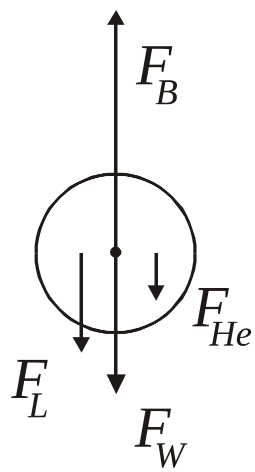
We've already calculated the weight of the cork, ***w***.

All we have to do is calculate the buoyant force, this is different than when the cork was floating because the entire cork is under water. So we use the cork's entire volume to find F_B.

Now we can find the force

Practice Problem:

A large 9.0 m radius spherical balloon is filled with helium. The mass of the balloon bag and the little basket thingee that hangs underneath is 168 kg. How much additional weight can the balloon carry (assume it is at sea level)?



The fluid that is displaced is air, so we can easily find the buoyant force.

Let's look at a FBD:

The sum of the forces must equal zero, this is the point where the upward force (the buoyant force) is equal to the total downward force – the weight of the bag, basket, and helium:

The forces are: F_B (buoyant force), ***w*** (weight of bag and basket), F_{He} (weight of helium), and the lift (lifting force) F_L (weight that is to be lifted).

$$F_B - F_W - F_L - F_{He} = 0 \qquad F_L = F_B - F_W - F_{He}$$

Volume of balloon:

We already know ***w*** (weight of bag and basket). We can now calculate the buoyant force.

We'll have to look up the density of the air and use that to find the buoyant force.

Next we have to find the weight of the helium. We have to look up its density as well.

Now we can find the additional weight the balloon can lift.