Fluids
Buoyancy

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Last time

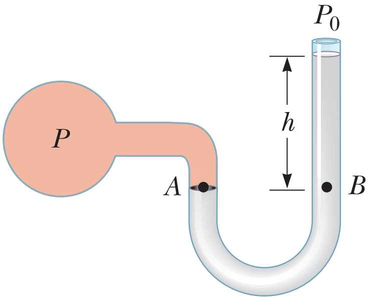
- pressure and depth
- Pascal's principle
- measurements of pressure

Overview

- buoyancy and Archimedes' principle

Manometer

The pressure being measured, P, can be compared to atmospheric pressure P_0 by measuring the height of the incompressible fluid in the U-shaped tube.

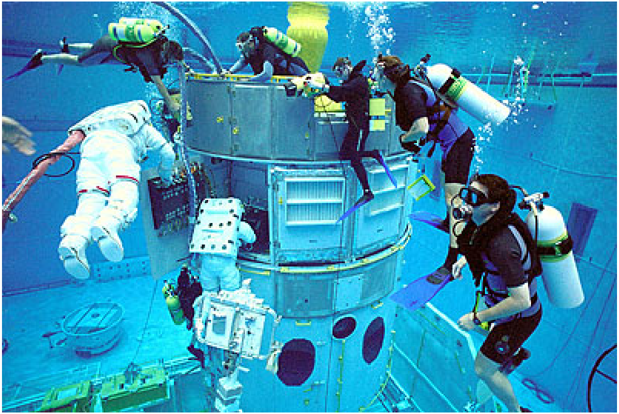


If h is positive, $P > P_0$, if "negative", $P < P_0$.

$P - P_0$ is called the **gauge pressure**.

Buoyancy

Astronauts training in their spacesuits:



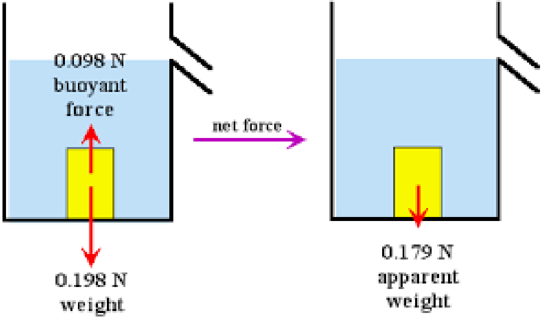
The total mass of NASA's EMU (extravehicular mobility unit) is 178 kg. Why does training underwater make maneuvering in the suits easier?

[1]Picture from Hubblesite.org.

Buoyancy

The apparent weight of submerged objects is less than its full weight.

For an object that would float, but is held underwater, its apparent weight is negative!



There is an upward force on an object in a fluid called the **buoyant force**.

Buoyancy

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Consider a rectangular object of height h and base area A with its top edge at a depth d.

The force on each of the four sides will be equal.

The force on the bottom will be $(P_0 + \rho g(h + d))A$.

The force on the top will be $(P_0 + \rho gd)A$.

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The force on the top will be $(P_0 + \rho g d)A$.

There will be a net upward force from the pressure difference!

Buoyancy

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Buoyancy

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$$\begin{aligned} F_{\text{buoy}} &= F_{\text{up}} - F_{\text{down}} \\ &= (P_0 A + \rho g (h + d) A) - (P_0 A + \rho g d\, A) \\ &= \rho g h A \\ &= \rho g V_{\text{obj}} \end{aligned}$$

because the volume of the submerged block is $V_{\text{obj}} = hA$.

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because the volume of the submerged block is $V_{\text{obj}} = hA$.

Notice that $\rho V_{\text{obj}} = m_f$, the **mass of the displaced fluid**.

(We are assuming ρ is constant.)

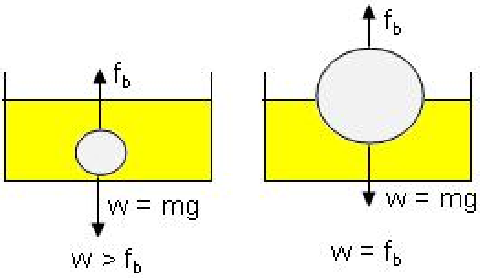
Buoyancy and Archimedes' Principle

Archimedes' Principle

The buoyant force on an object is equal to the weight of the fluid that the object displaces.

Logically, if a brick falls to the bottom of a pool it must push an amount water equal to its volume up and out of the way.

Buoyancy and Archimedes' Principle



For a fully submerged object the buoyant force is:

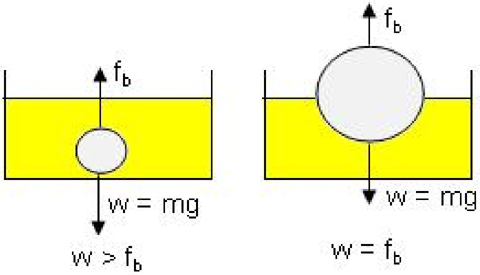
$$F_{\text{buoy}} = \rho_f V_{\text{obj}}\, g$$

where ρ_f is the mass density of the fluid and V_{obj} is the volume of the object.

$\rho_f\, V_{\text{obj}}$ is the mass of the water moved aside by the object.

Buoyancy and Archimedes' Principle

An object that floats will displace less fluid than its entire volume.



For a floating object:

$$F_{\text{buoy}} = \rho_{\text{f}} V_{\text{sub}}\, g$$

where V_{sub} is the volume of the part of the object underneath the fluid level only.

Sinking and Floating

Will a particular object sink or float in a particular fluid?

- If the object is *less dense* than the fluid it will float.
- If the object is *more dense* than the fluid it will sink.
- If the object and the fluid have the same density if will neither float or sink, but drift at equilibrium.

Sinking and Floating

Since the *relative* density of the object to the fluid determines whether it will sink or float, we sometimes use the notion of **specific gravity**.

The specific gravity of an object relates its density to the density of water (or occasionally other liquids):

Specific gravity, SG

of a sample is the ratio of its density to that of water.

$$SG = \frac{\rho_{\text{sample}}}{\rho_{\text{water}}}$$

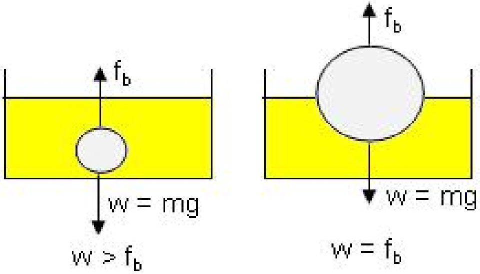
Often referenced in brewing!

Sinking and Floating

A floating object displaces a mass of fluid equal to its own mass!

(Equivalently, a weight of fluid equal to its own weight.)

This also means that $\rho_f V_{sub} = m_{obj}$.



Questions

Military ships are often compared by their *displacements*, the weight (or mass, depending on context) of water they displace.

The *USS Enterprise* was an aircraft carrier (now decommissioned).

Displacement: 94,781 tonnes (metric tons), fully loaded.

1 tonne = 1000 kg

What is the mass of the fully loaded USS Enterprise in kgs?

[2] Hewitt, page 246.

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Question

Quick Quiz 14.4[2] You are shipwrecked and floating in the middle of the ocean on a raft. Your cargo on the raft includes a treasure chest full of gold that you found before your ship sank, and the raft is just barely afloat. To keep you floating as high as possible in the water, should you
(i) leave the treasure chest on top of the raft,
(ii) secure the treasure chest to the underside of the raft, or
(iii) hang the treasure chest in the water with a rope attached to the raft?
(Assume throwing the treasure chest overboard is not an option you wish to consider.)

A option (ii) is the best

B option (iii) is the best

C options (ii) and (iii) would be the same, better than (i)

D All would be the same

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Buoyancy in Air

Buoyancy in air works the same way as in liquids:

$$F_{\text{buoy}} = \rho_{\text{f}} V_{\text{obj}}\, g$$

If an object is less dense than air, it will float upwards.

However, in the atmosphere, the density of air varies with height.

Buoyancy in Air

[1]Photo by Derek Jensen, Wikipedia.

Buoyancy in Air

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About 1.18 N.

Summary

- buoyancy and Archimedes' principle

Test Tuesday, April 17, in class.

Collected Homework due Monday, April 16.

(Uncollected) Homework Serway & Jewett:

- Previous: Ch 14, onward from page 435. Probs: 25, 27, 29, 35, 36, 65, 71, 73,(buoyancy questions)
- Ch 14, onward from page 435, OQs: 3, 5, 9, 13; CQs: 9, 14; Probs: 43, 49, 53, 85