Fluids, Thermodynamics, Waves, & Optics
Lab 1
Buoyancy

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Overview

- Brief discussion of laboratory work
- Theory: Buoyancy
- Procedure

Why we do lab work

To confirm or disprove hypotheses

To get insights for new hypotheses, by hands on experience

Assessment

- lab worksheets each week - assessment in groups, and sometimes individual questions
- final week may have a special project (?)

Doing the Labs

After we cover the lab lecture, we will split up into groups in Zoom breakout rooms.

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I will move between breakout rooms to check in with you and answer questions.

Doing the Labs: Roles

It is hard to look at many files and applications on one screen, so work together.

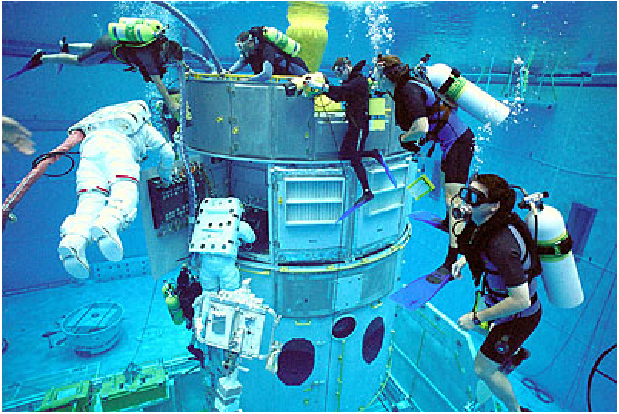
Three roles, one for each person:

- "director" - reads the instruction sheet out loud to the others and says what to do
- "operator" - runs the PhET sim while sharing their screen to the group, so everyone can see what's happening
- "recorder" - records experimental values and writes and uploads the Canvas Assignment. This person should share their screen while you discuss the answers to the questions.

Each week, change who does which role.

Theory: Buoyancy

Astronauts training in their spacesuits:

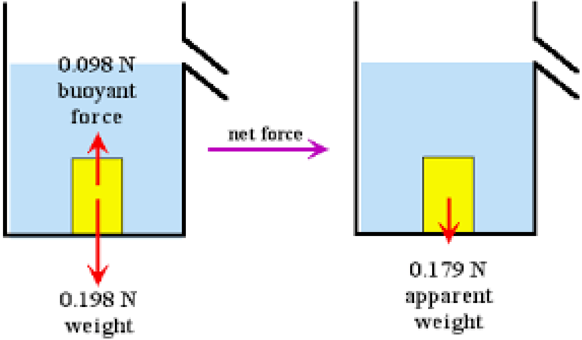


The total mass of NASA's EMU (extravehicular mobility unit) is 178 kg. Why does training underwater make maneuvering in the suits easier?

[1] Picture from Hubblesite.org.

Buoyancy

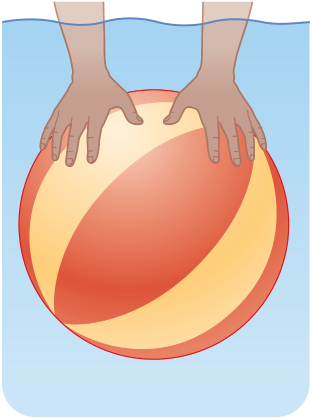
The apparent weight of a submerged object is less than its full weight.



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

Buoyancy

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



In that case, the **buoyant force** is larger than the weight of the object.

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

Buoyancy

How big will the upward force be?

$$F_{\mathrm{B}} = F_{\mathrm{up}} - F_{\mathrm{down}}$$

Buoyancy

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\begin{aligned}
F_{\mathrm{B}} &= F_{\mathrm{up}} - F_{\mathrm{down}} \\
&= (P_0 A + \rho g (h+d) A) - (P_0 A + \rho g d\, A) \\
&= \rho g h A \\
&= \rho g V_{\mathrm{obj}}
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Notice that $\rho V_{\mathrm{obj}} = m_f$, the **mass of the displaced fluid**.

(We are assuming ρ is constant.)

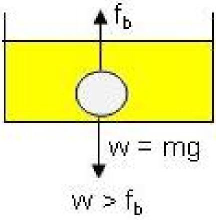
Buoyancy and Archimedes' Principle

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:

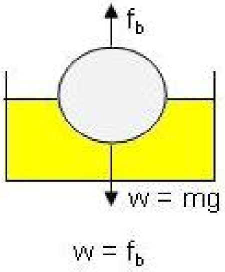
$$F_B = \rho_f V_{obj}\, g$$

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

$\rho_f\, V_{obj}$ 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:

$$F_B = \rho_f V_{sub}\, g$$

where V_{sub} is the volume of the *submerged* part of the object only.

Buoyancy and Archimedes' Principle

In general, we can write:

$$F_B = \rho_f V_{sub}\, g$$

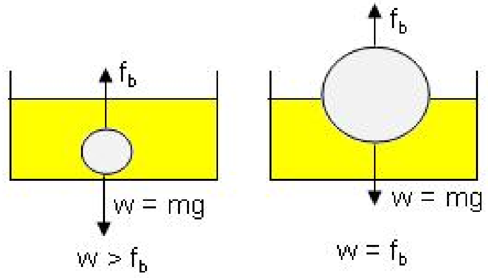
where V_{sub} is the volume of the *submerged* part of the object only.

However, if the object is completely submerged, then $V_{sub} = V_{obj}$.

Sinking and Floating

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

It sinks if its weight, F_g, is greater than the weight of the fluid it can displace.



Sinking and Floating

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- 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.

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

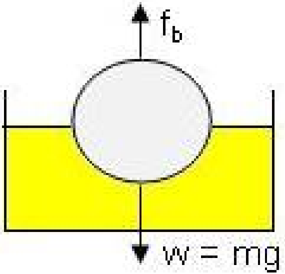
Often referenced in brewing!

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 $\rho_f V_{sub} = m_{obj}$.



w = f_b

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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Buoyancy in Air

Buoyancy in air works the same way as in liquids:

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

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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(In the Phet sim, this is neglected!)

Doing the Lab

We'll split into breakout rooms.

Load up the Buoyancy PhET sim and try it out!