Conceptual Physics
Matter
Liquids
Gases

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Last time

- atomic structure
- forms of matter
- solids
- density
- elasticity
- liquids & pressure

Overview

- liquids
- pressure
- surface tension
- buoyancy and Archimedes' Principle
- Pascal's principle
- gases
- the atmosphere
- Boyle's law

Liquids

liquid

a state of matter where the constituent particles are free to move around relative to one another, but the substance is nearly incompressible. Volume is fixed, but shape is not.

A solid that is heated will *melt* to form a liquid.

If that liquid is further heated it will *boil* to form a gas.

Both liquids and gases can flow, but the density of a substance in its liquid state is close to that in its solid state. For gases the density can vary.

Pressure

Most liquids maintain nearly constant volume whatever the pressure.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

$$P = \frac{F}{A}$$

Pressure is measured in Pascals, Pa; 1 Pa $=$ 1 N/m^2.

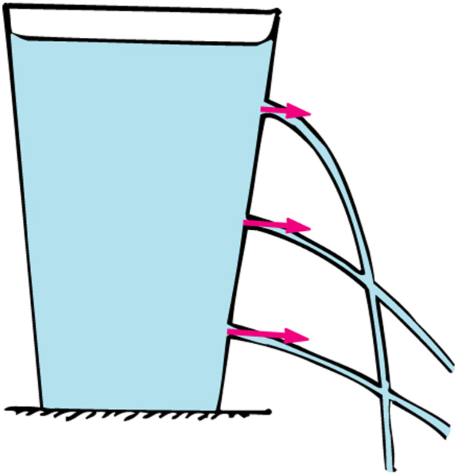
Atmospheric pressure is 101.3 kPa, or 1.013×10^5 Pa.

Since the Pascal is a small unit (even 1 atmosphere is $\sim 10^5$) sometimes *atmospheres* are also used as a unit of pressure.

1 atmosphere $= 1.013 \times 10^5$ Pa

Pressure varies with Depth

$$P_{\text{liq}} = \rho g h$$



Surface Tension

The H_2O molecules that make up water are slightly polar and attract one another.

This means that water droplets tend to arrange themselves to minimize their surface area.

cohesion

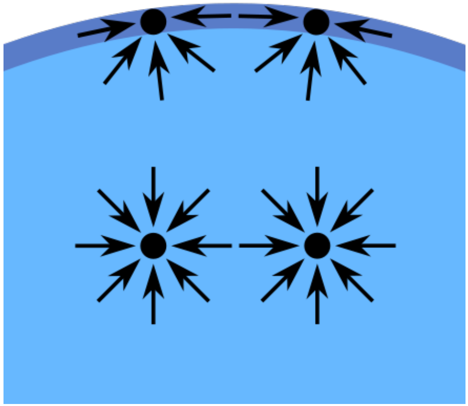
The attraction between like molecules

adhesion

The attraction between molecules of different substances

Water in air behaves as if it is covered with an elastic membrane because the cohesive forces between the water molecules are stronger than the adhesive forces between water and air.

Surface Tension



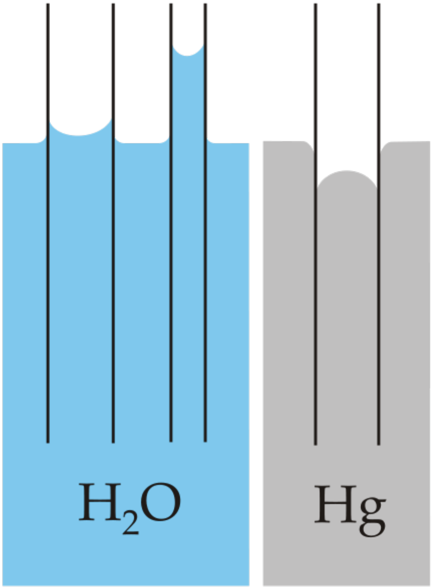
Mensicus

A meniscus, or curvature of a liquid surface happens when a water droplet is in air, or when water is in a glass beaker.

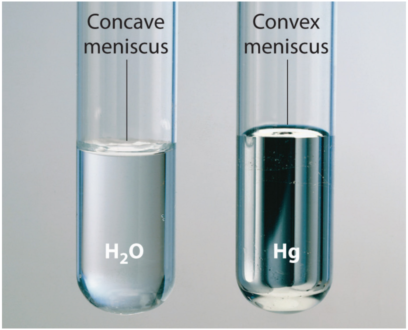
Adhesive forces between water and glass are stronger than cohesive forces within the water, so the water tends to stick to the glass.

This effect can also be used to draw water up in a glass tube.

Capillary Action

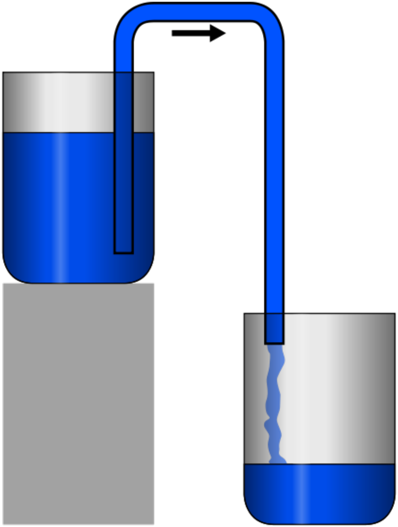


Mensicus



[1]https://chem.libretexts.org/Core/Physical_and_Theoretical_Chemistry

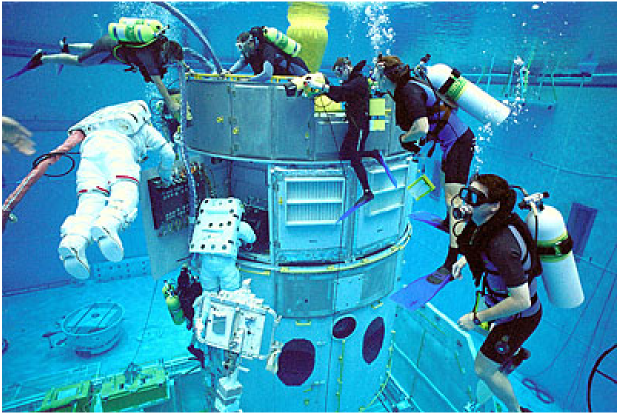
Siphoning



[1]Figure from Wikipedia.

Buoyancy

Astronauts training in their spacesuits:



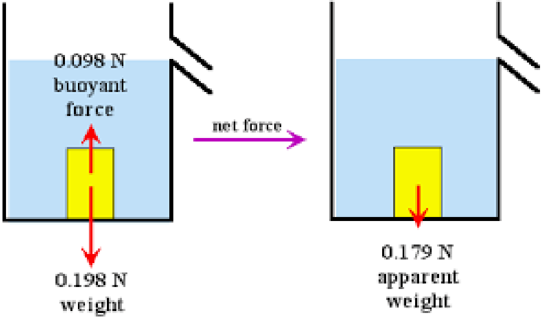
The total mass of NASA's EMU (extravehicular mobility unit) is 178 kg. Why does training underwater make maneuvering in the suits easier?

[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 and Archimedes' Principle

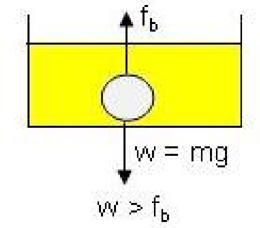
Archimedes' Principle

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

$$F_{\text{buoy}} = W_{\text{df}}$$

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



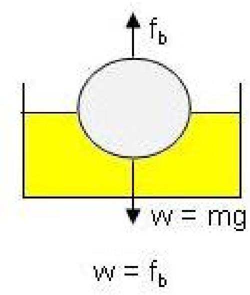
For a fully submerged object the weight of the displaced fluid is the product of the density of the fluid, ρ_f, the volume of the object, V_{obj}, and g, so:

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

$\rho_f\, V_{obj}$ 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:

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

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?

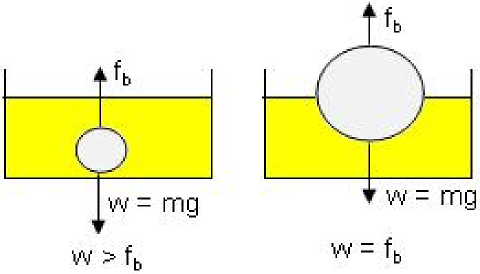
- If the object is *less dense* than the fluid it will float.
- If the object is *more dense* than the fluid it will sink.
- If the object and the fluid have the same density if will neither float or sink, but drift at equilibrium.

Sinking and Floating

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

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

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



Whether it sinks or floats, always:

$$F_{buoy} = W_{df}$$

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?

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Problem # 8, page 246.

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Ans: 0.1 m^3

Pascal's Principle

(Or, how hydraulic systems work.)

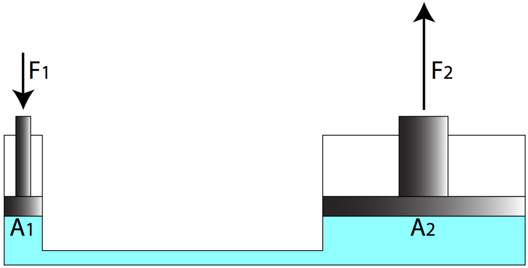
Liquids are (mostly) incompressible.

If you push on a piston at one end of a pipe you will move the liquid at the far end.

Pascal's Principle

A change in pressure at any point in an enclosed fluid at rest is transmitted undiminished to all points in the fluid.

Pascal's Principle



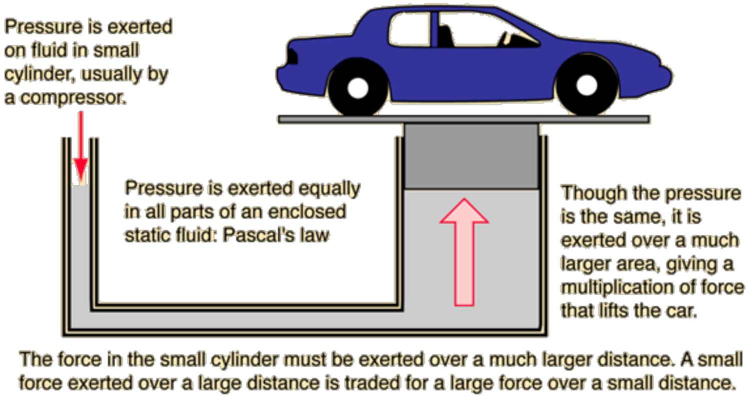
Since the pressures at the left end and the right end are the same:

$$P_1 = P_2$$
$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

Since $A_2 > A_1$, $F_2 > F_1$.

Pascal's Principle

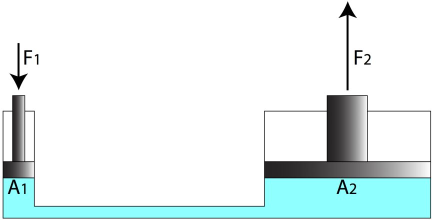
This has applications:



[1]Figure from hyperphysics.phy-astr.gsu.edu.

Question

If a pair of pistons are connected on either end of a hydraulic tube. The first has area 0.2 m^2 and the second has an area of 4 m^2.



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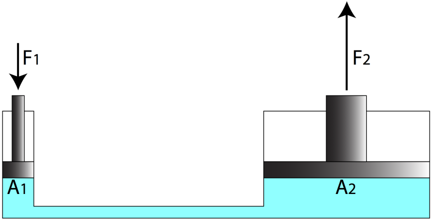

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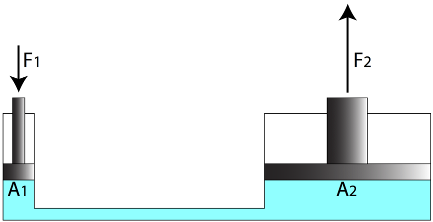

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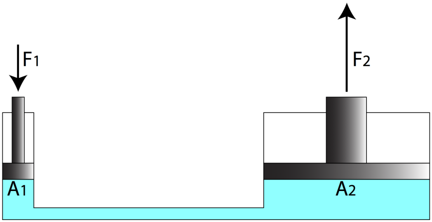

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Ans: $F_2 = 600$ N

If the first piston is depressed a distance of 1 m by the 30 N force, how far does the second piston rise?
Ans: $0.05\text{m} = 5\text{cm}$

Gases

gas

a state of matter where the constituent particles are vastly separated from one another and free to move around.

A liquid that is heated will *boil* to form a gas.

A gas heated much further will form a *plasma*.

Both liquids and gases can flow, but the density of gases can vary and they are readily compressible.

The large distances between individual molecules or atoms is why most gases are transparent.

Elemental Gases

- hydrogen (H_2),
- nitrogen (N_2)
- oxygen (O_2)
- fluorine (F_2)
- chlorine (Cl_2)
- helium (He)
- neon (Ne)
- argon (Ar)
- krypton (Kr)
- xenon (Xe)
- radon (Rn)

The Atmosphere

We are living in a sea of air.

It is held in place by Earth's gravity and made up of:

- nitrogen, N_2, $\sim 78\%$
- oxygen, O_2, $\sim 21\%$
- argon, Ar, $\sim 1\%$
- carbon dioxide, CO_2, $\sim 0.4\%$

It also contains less that 1% water vapor.

Layers of the Atmosphere

[1] Picture shot from the ISS, courtesy of NASA Earth Observatory.

Air Pressure

Just like liquids, gases also exert pressure on their surroundings.

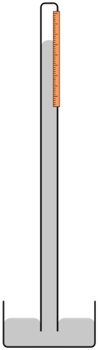
Atmospheric pressure at sea level is 101.3 kPa.

Atmospheric pressure falls with increasing altitude.

Atmospheric pressure fluctuates locally from place to place, day to day.

Barometers

Barometers are devices for measuring local atmospheric pressure.



Typically, simple barometers are filled with mercury, which is very dense.

The weight of the mercury in the tube exerts the same pressure as the surrounding atmosphere. On low pressure days, the level of the mercury drops. On high pressure days it rises.

Boyle's Law

Suppose you seal a fixed mass of gas in a container.

If you compress it, you will decrease the volume, but increase the pressure. If you let it expand, you increase the volume but decrease the pressure.

For a fixed mass of gas at a constant temperature:

$$P_1 V_1 = P_2 V_2$$

This is Boyle's Law.

Summary

- liquids
- pressure
- surface tension
- buoyancy
- Pascal's principle
- gases
- the atmosphere

Talks! Aug 8-9.

Homework Hewitt,

- Ch 13, onward from page 243. Exercises: 15, 25; Problems: 3, 5, 7
- Ch 14, onward from page 262. Ranking 1; Exercises: 9, 17, 19, 40, 47, (53); Problems: 1