Prelab: Pressure and flow

Everyday thing: Sucking liquid through a straw, using suction cups to attach stuff to your windscreen, the hydraulic systems in your car, gas pumps lift petrol from an underground tank and pump it into your gas tank.

It is physics: all these things exploit pressure and flow in fluids.

Pressure

Pressure is the force excerted on a certain area:

$$\text{pressure} = \frac{\text{force}}{\text{area}}$$

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

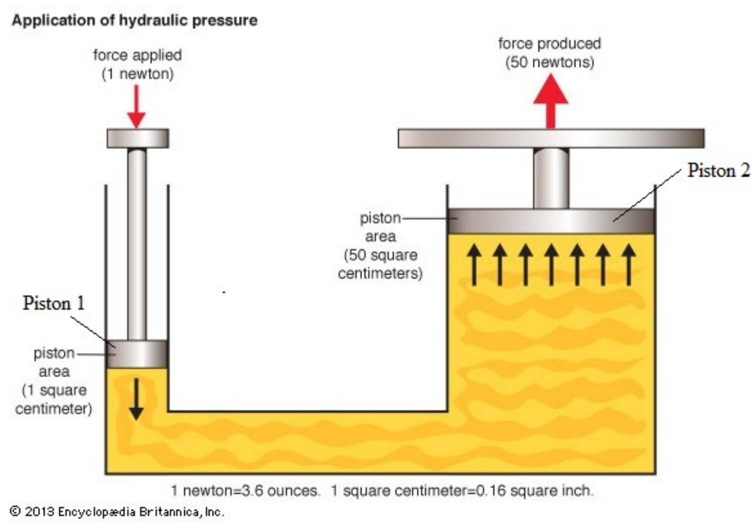
The SI unit of pressure is the **Pascal** (**Pa**) which is the same as **N/m²**. This is a very "small" unit in everyday terms. The atmospheric pressure, which pressure due to the weight of the air above us, is about **100,000 Pa** or **100 kPa** at sea level.

Pressure is a useful concept for fluids and gases, because all other things equal, a fluid will maintain a **constant pressure** throughout.

This allows hydraulics to work: suppose you have a small piston of area A_1, on which you apply a force F_1, and a large piston of area A_2. Since the pressure on both sides is equal, you will get for the force F_2 on the second piston:

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

In other words, if the large piston has a 50x area, you only need to apply 1/50th of the force to the small piston to balance the force on the large piston.



Suction cups

When a suction cup is pressed to a smooth surface two things happen.

First, the air is evacuated from the concave chamber. Once most of the air is evacuated, there is air pressure disequilibrium. The ambient air pressure is greater than the pressure inside the chamber and therefore exerts a force on the suction cup.

Second, the force exerted by the greater ambient air pressure presses the cup onto the surface, forming a hermetic seal (impenetrable to air). A hermetic seal does not allow air to pass between the inner chamber and the ambient, so the disequilibrium does not correct itself.

This is why the suction is successful.

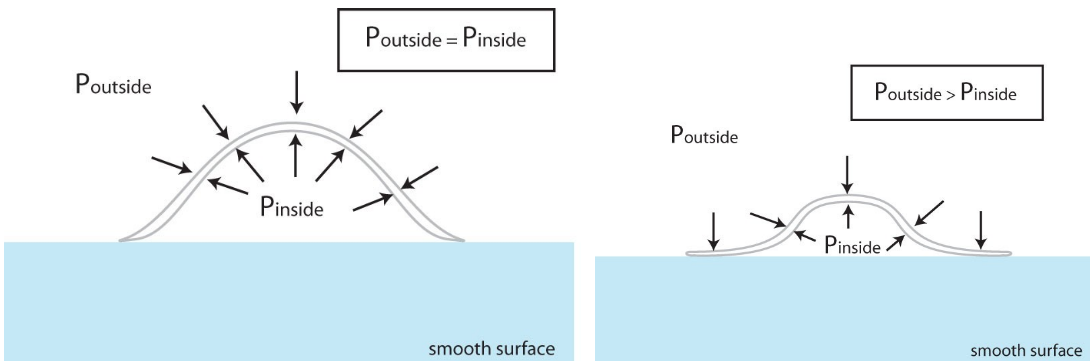


Figure 1: The left figure is the suction cup before being pressed. The inside and outside pressures are the same, so the cup can be easily removed. The right figure is the suction cup after being pressed. The inside and outside pressures are not the same, and so the cup has suction to the surface.

If a person wants to remove a suction cup from a smooth surface they must pull with a force greater than the pressure difference between the chamber and the ambient air.

Remember that force is pressure times area. This means that as the area increases, the force increases. That is why with a larger suction cup, the force you needed to pull it off was greater than with a smaller suction cup.

Moving fluids and Bernoulli's principle

If fluids move, things get a little more complicated.

The easiest way to think of what will happen to a fluid is to think in terms of conservation of energy: remember that if you climb a slide, initially you acquired **potential energy** by overcoming gravity and climbing up the ladder. Then, as you slide down the slide that potential energy is transformed into **kinetic energy** (energy due to movement). The total energy, that is potential energy plus kinetic energy, does not change in the process of sliding.

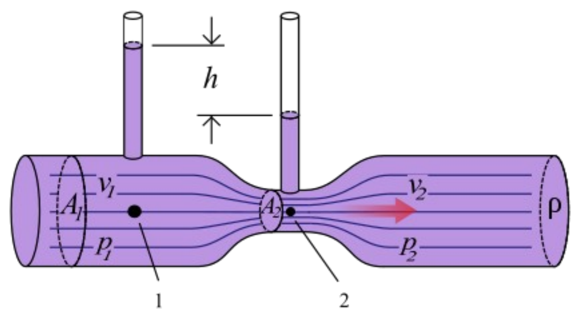
A similar thing happens in fluids, where there is a third term, which relates to the fact that if you try to compress the fluid, it will push back, exerting **pressure**. Again, the total energy, coming from gravity, flow and pressure, does not change:

(kinetic energy) + (potential energy) + (energy due to pressure) = const.

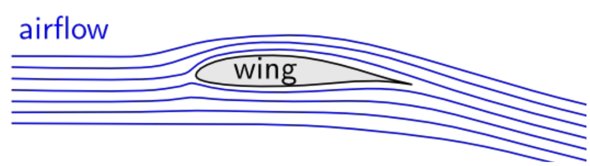
$$\frac{1}{2}\rho v^2 + \rho g h + p = \text{const}$$

In the above equation ρ is the density of the fluid, v is the velocity, h is the height, g is the strength of gravity and p is pressure. This is known as **Bernoulli's principle**.

This has an interesting consequence: if we have a constriction in our pipe, the water has to flow more quickly through it. This increases the kinetic energy (first term). So to balance it, the pressure of the fluid drops in the constricted section (this is known as the **Venturi effect**).



It also explains part of the reason why airplanes fly. The air above the wing is slightly "squashed", which means it has to flow faster. This however means that the pressure on the top of the wing will be lower than on the bottom of the wing, which pushes the wing upwards and generates lift. (Note however that this is not the main effect generating lift in a typical airplane.)



It also explains water pressure: as we dive down in a pond, we move into waters with a lower potential energy (second term). In order to balance this, the water has a higher pressure the deeper we dive.

--> Play around with this simulation: https://phet.colorado.edu/en/simulation/under-pressure

Add a pressure gauge and use the faucets to add and remove water, then move the pressure gauge around.