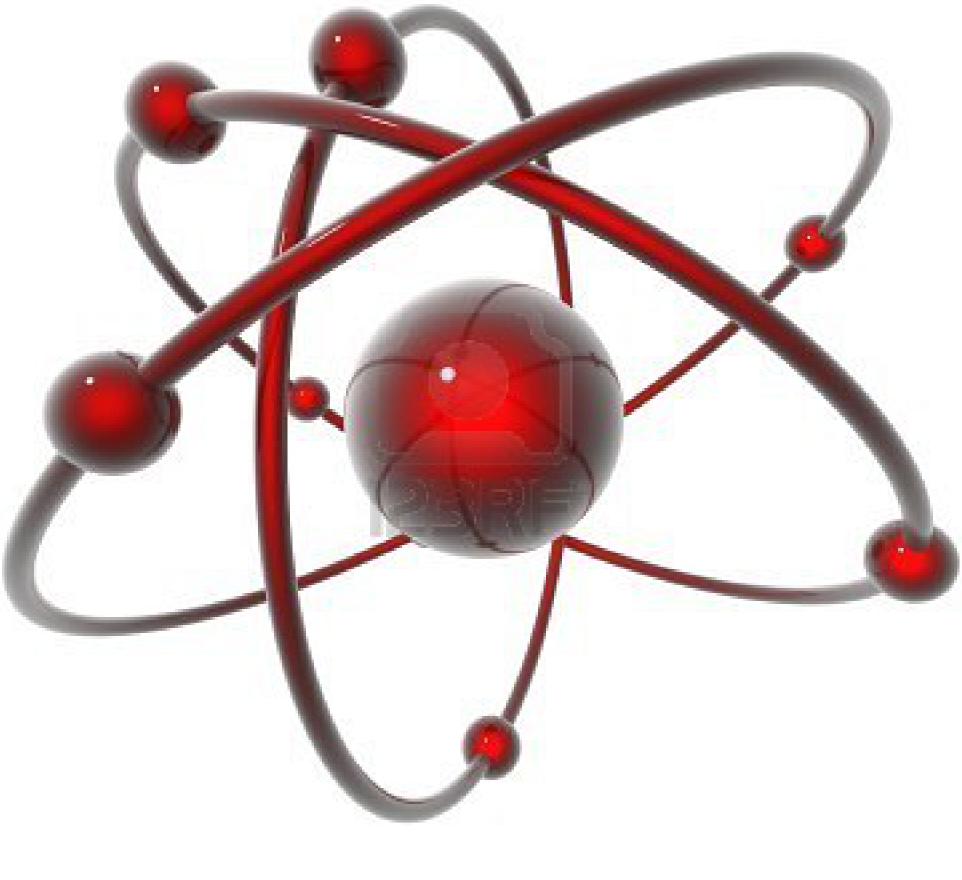
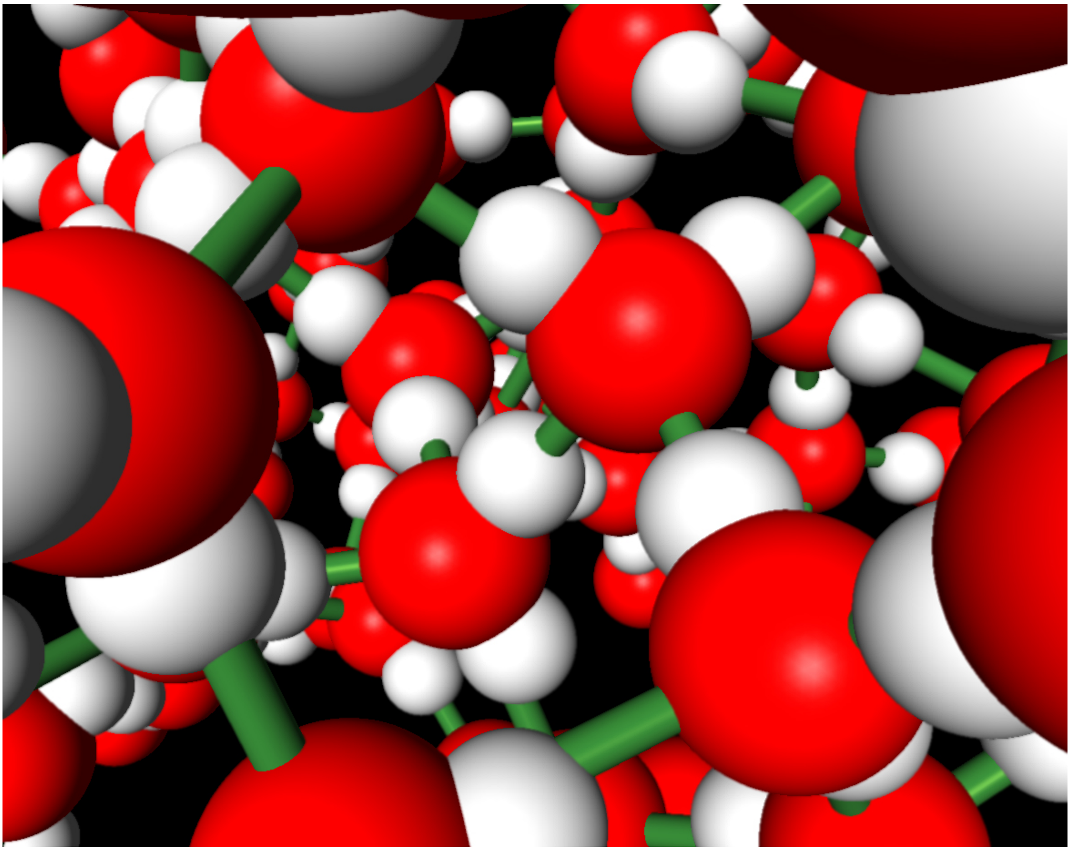
Chapter 2

Diving Physics and Chemistry



This chapter describes the laws of physics and chemistry which are concerned with diving and affect humans in the water. Understanding of principles in this chapter is essential for safe diving.

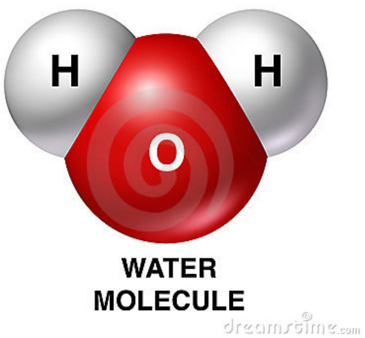
The human body is adapted to conditions on land where the pressure is approximately 1 bar. On this pressure our body functions normally, without any difficulties. In the water the pressure rises, so we need special equipment which allows us to stay underwater longer and safer without permanent consequences on our health. Two major problems our body faces underwater are the affects of higher pressure and problems related to the gas mixture (mixture which we breath from the dive tank) under pressure. In order to understand those problems we first need to learn the basic physical and chemical characteristics of water in which the divers stay, and air which the divers breath.

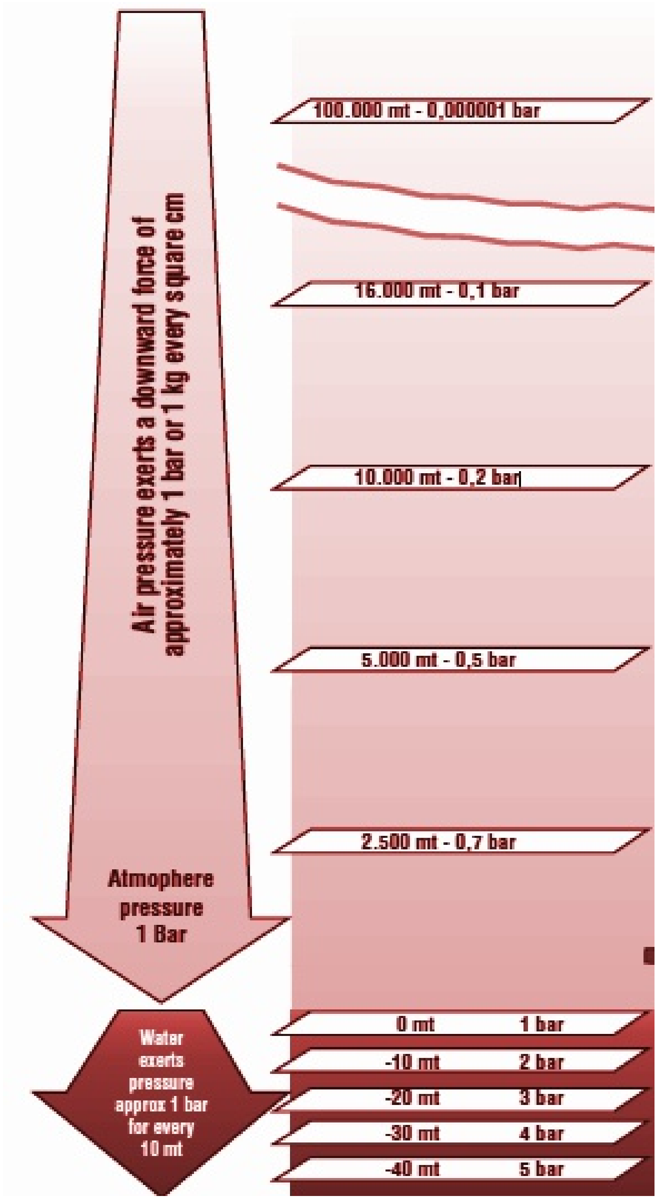


water molecules

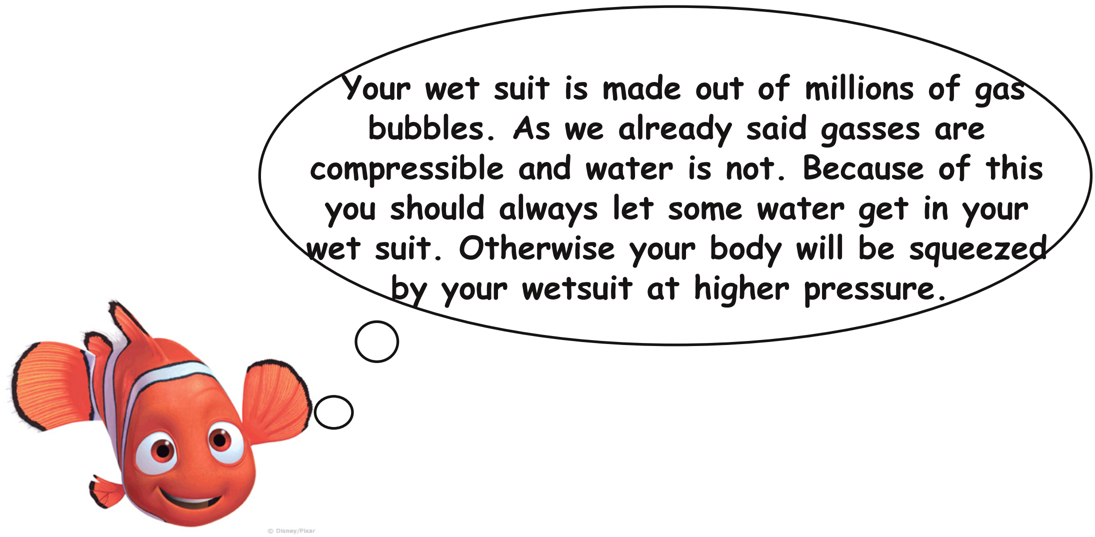
Physical and chemical characteristics of water

Water is made of two hydrogen and one oxygen atom with a mixture of gasses, minerals and other elements. It is a fluid which changes its shape based on the container it is placed in. Sea water has its salinity which gives it bigger mass and density than fresh water.

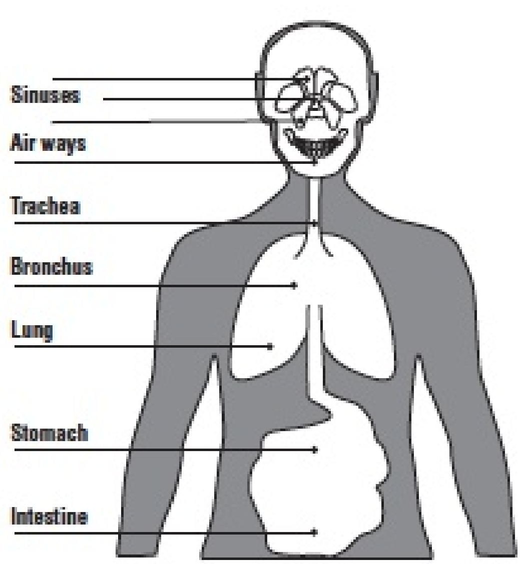


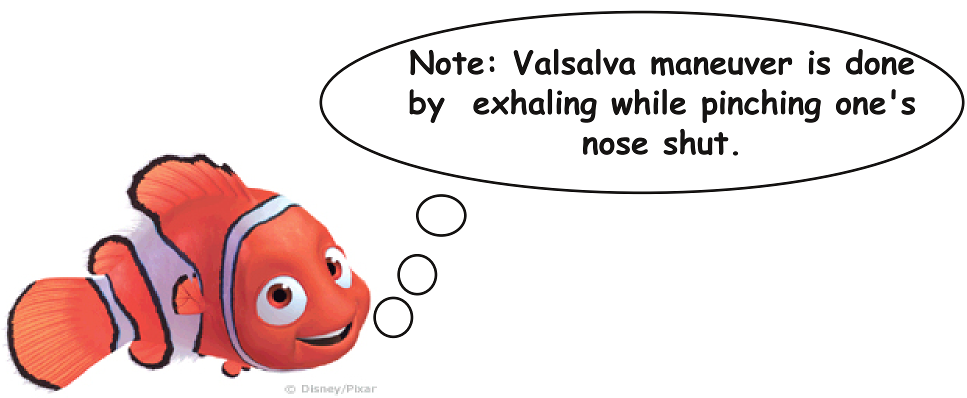


The volume of water changes directly proportional to the pressure, so it is incompressible, unlike gasses. Because of this fact the pressure in water rises 1bar every 10 meters .



When we are exposed to higher pressure we feel the pressure only on the parts of our body which have cavities filled with air (because air is compressible). Thus we feel the pressure on our eardrum (we equalize the pressure by valsalva maneuver), lungs (we equalize the pressure by breathing air under the same pressure from the regulator) and sinuses (the air under pressure enters sinuses independently).

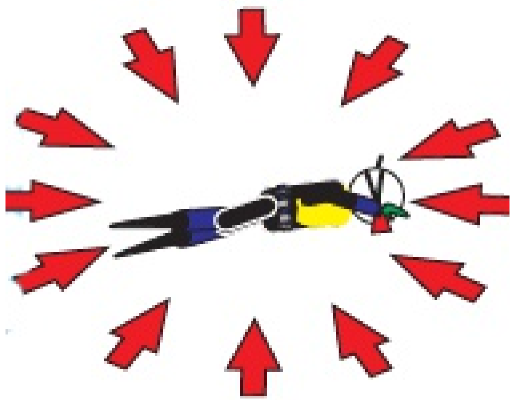




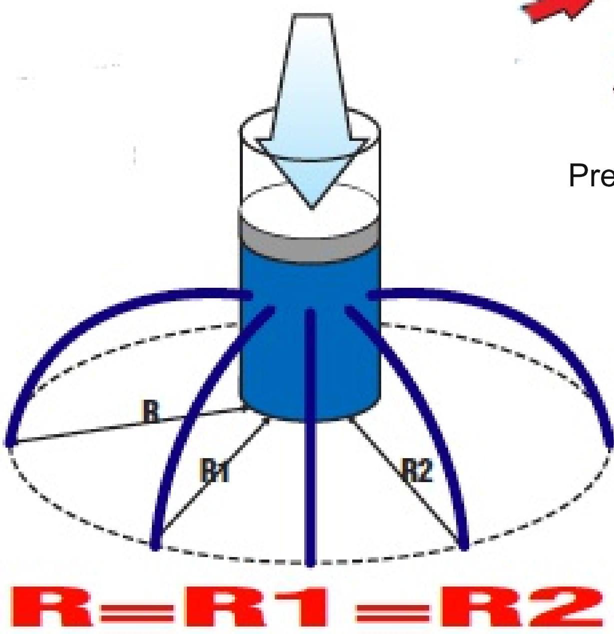
Unlike solids, pressure in fluids (gasses and liquids) is transferred uniformly in all directions. This is explained by Pascal's law which states :

“If pressure is applied to a non-flowing fluid in a container, then that pressure is transmitted equally in all directions within the container”

Thus, the pressure of the air breathed from a cylinder is transmitted in all directions and to all cavities with the same strength, and a body immersed in a fluid is not crushed by the weight of the fluid because the pressure tends to surround it by exerting the same force on its whole surface. For this reason it is possible to dive on big depths without being crushed by the weight of the water.



Pressure envelops a diver



Pressure is transferred uniformly in all directions

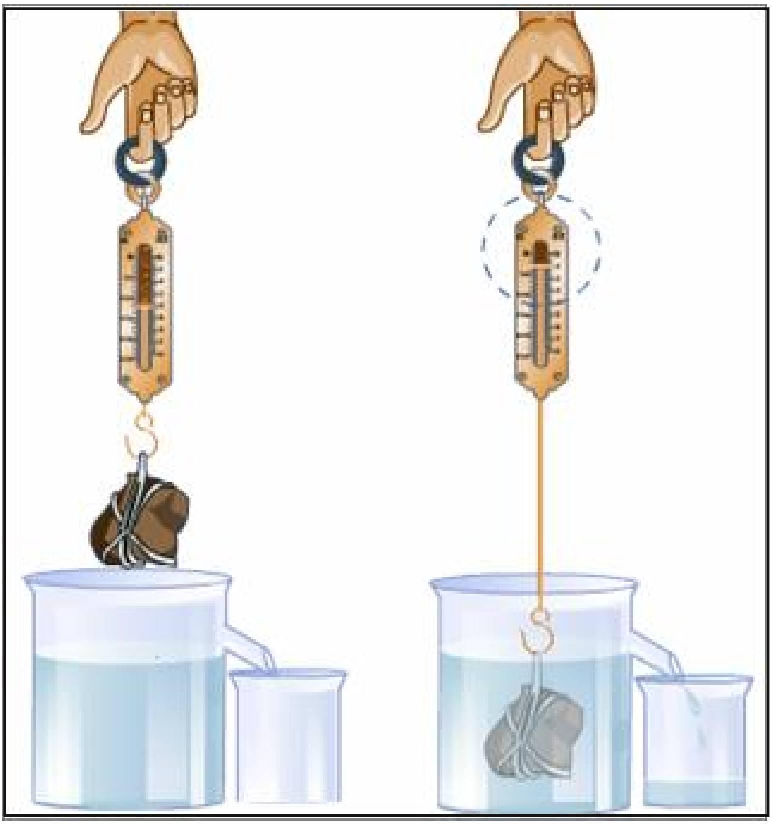
Buoyancy of objects in water

Buoyancy is the tendency of a body to float caused by the upthrust (vertical force) described in Archimede's law.

Archimede' s law states:

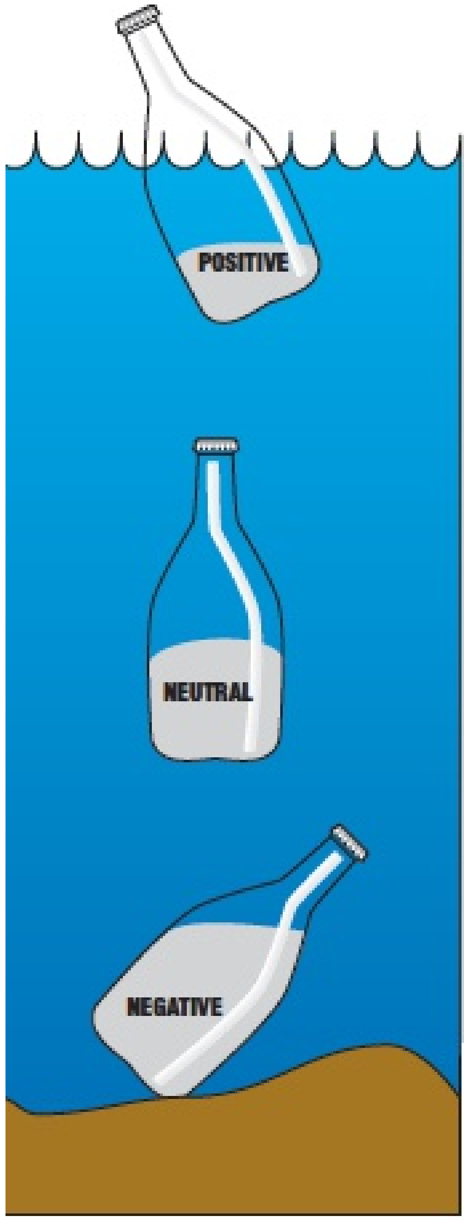
" A body immersed in water will receive an upthrust equal to the weight of water it displaces"

Upthrust = [volume of the part of the solid immersed in fluid] x [density of fluid] x gravitational acceleration.



The weight of the water displaced by the rock is equal to the upthrust

This law describes buoyancy. Some common terms to describe buoyancy are:



Positive Buoyancy: the tendency of the body to float. In this case the weight of the body is less than the upthrust force

Neutral Buoyancy: the body neither floats nor sinks. In this case the upthrust and the weight of the body are the same

Negative Buoyancy: the tendency of the body to sink. In this case the weight of the body is bigger than the upthrust force

Every diver tends to have neutral buoyancy by achieving equilibrium between the body, the equipment and the weights.

Neutral balance means more safety, control and comfort underwater. In order to achieve neutral buoyancy we need to consider the relation between the volume and weight of: our body, the density of the liquid we dive in, and the equipment we dive with.

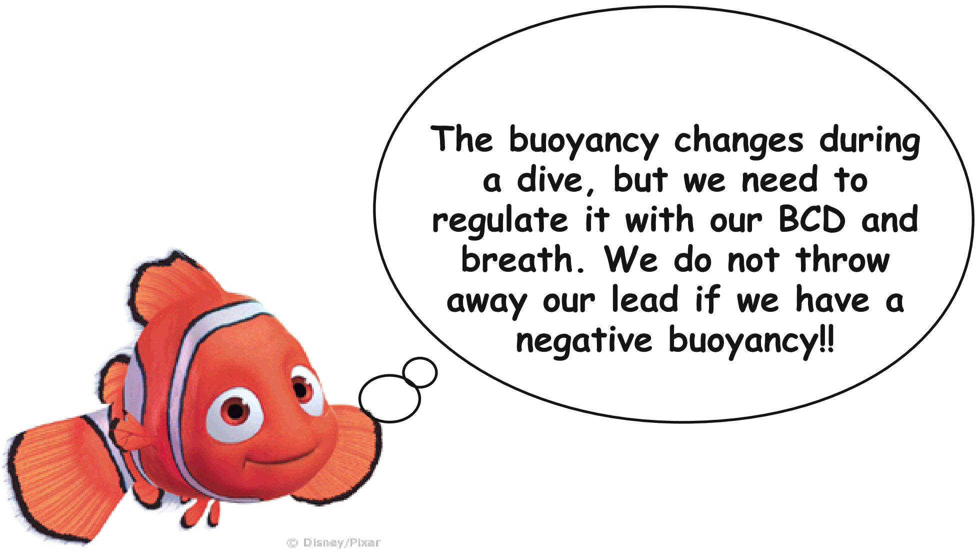
Every diver needs to asses how much weights he needs according to his own body shape, thickness of his suit (suit is made of millions of bubbles, so it has positive buoyancy), weight and number of diving cylinders (more cylinders equals more weight) he carries and the density of water he dives in (higher water density means bigger upthrust and more weights are needed to sink).

These divers are neutrally buoyanced and do not stick to the floor or go towards the surface

The diver may change his buoyancy in different ways. By adding weights to the weight belt, breathing in and out changes the volume of his lungs, and regulating the amount of air in the BCD by increasing or decreasing the volume of the BCD.

Note: *more volume = more upthrust, less volume = less upthrust.* If you are sinking (negative buoyancy) on descent (gasses compress on bigger pressure) you inflate the BCD (increase the volume of your BCD, thus causing bigger upthrust). If you are going towards the surface (positive buoyancy) on ascent (gasses expand on smaller pressure) you should deflate your BCD (less volume of air in the BCD equals less upthrust).

Note: It is better to have 1 kg lead more than less. Namely, on ascend you have less air in you cylinder and thus it weighs less. Divers always make safety stops or decompression stops. If not, they can get a bad disease or even die (see page 100). If you do not have enough lead, the upthrust will bring you to surface because of the reduced weight of the cylinder.

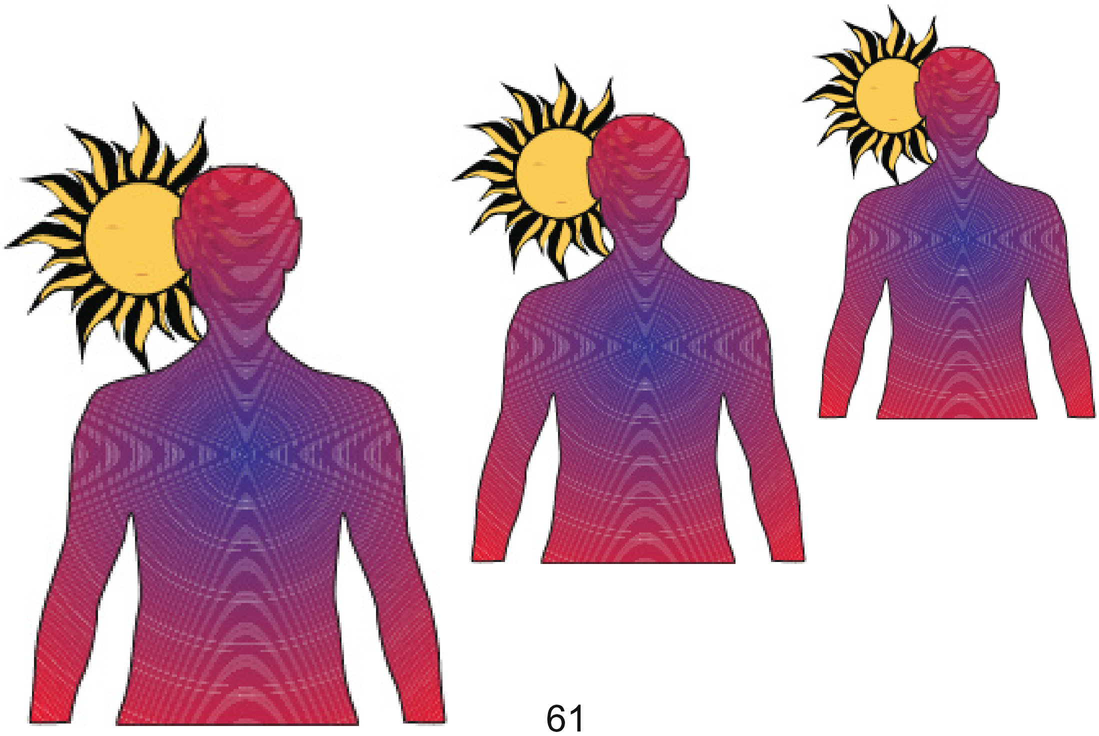


Water resistance

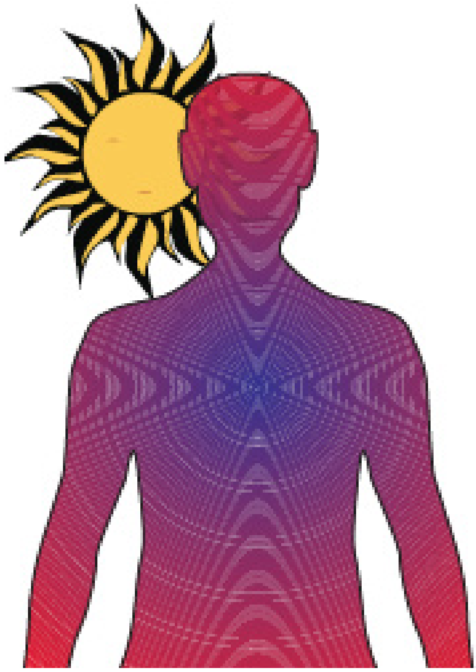
The bigger your surface area is, the bigger the resistance. Bigger resistance equals harder swimming and getting tired sooner. The smallest resistance is when you dive in a horizontal position. When you inflate your BCD the resistance increase because the surface area of the diver increases.

Heat loss in diving

Severe heat loss of body temperature leads to a condition called hypothermia. It is caused by a lowering of the body temperature below 34 degrees Celsius and can lead to serious heath problems. Hypothermia causes respiratory problems. It also reduces the brain and heart activity. It often results in disorientation and coma. It is very important to be properly equipped for dives. Never dive without a wet suit! If a diver gets hypothermia we need to remove the diver ‘s wet clothing, dry him, cover him with blankets, and keep him warm all over. Therefore, when you feel cold on a dive, tell that to your dive leader and start surfacing because the water is warmer at shallow waters. Remember, ALWAYS wear a wet suit!



Overheating in diving



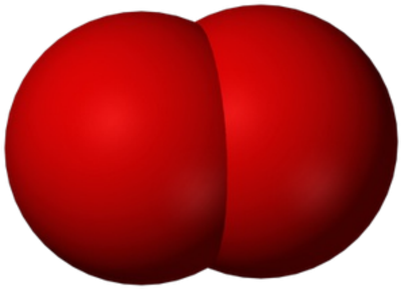
Overheating of the body is called HYPERTHERMIA. It occurs after excessive exposure to heat. This happens when a the diver stays under the sun for a considerable time. Symptoms such as headache, excessive sweating, respiratory difficulties, and even loss of consciousness may occur. The diver with hyperthermia should be undressed, taken to a cooler environment and given a lot of water to drink.

In order to wear your suit before getting to the location without overheating you need to let water in your suit. If the boat trip is very long then you can take off the upper part of the suit.

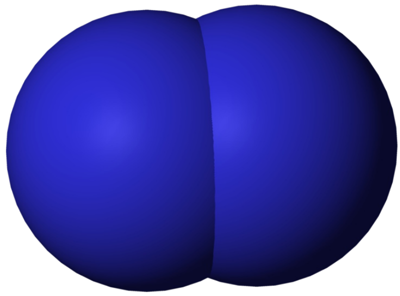
Properties of air and its components

Air is a mixture of gasses consisted of 21% Oxygen, 78% nitrogen and 0,03% carbon dioxide. These components have different properties which are important to know.

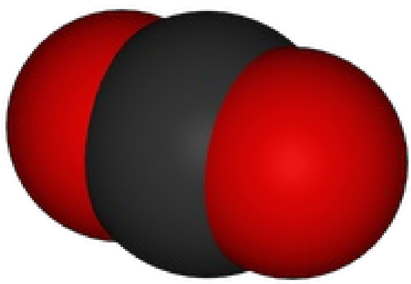
Oxygen is a colorless, scentless and tasteless gas which is one of the most important for breating and life.



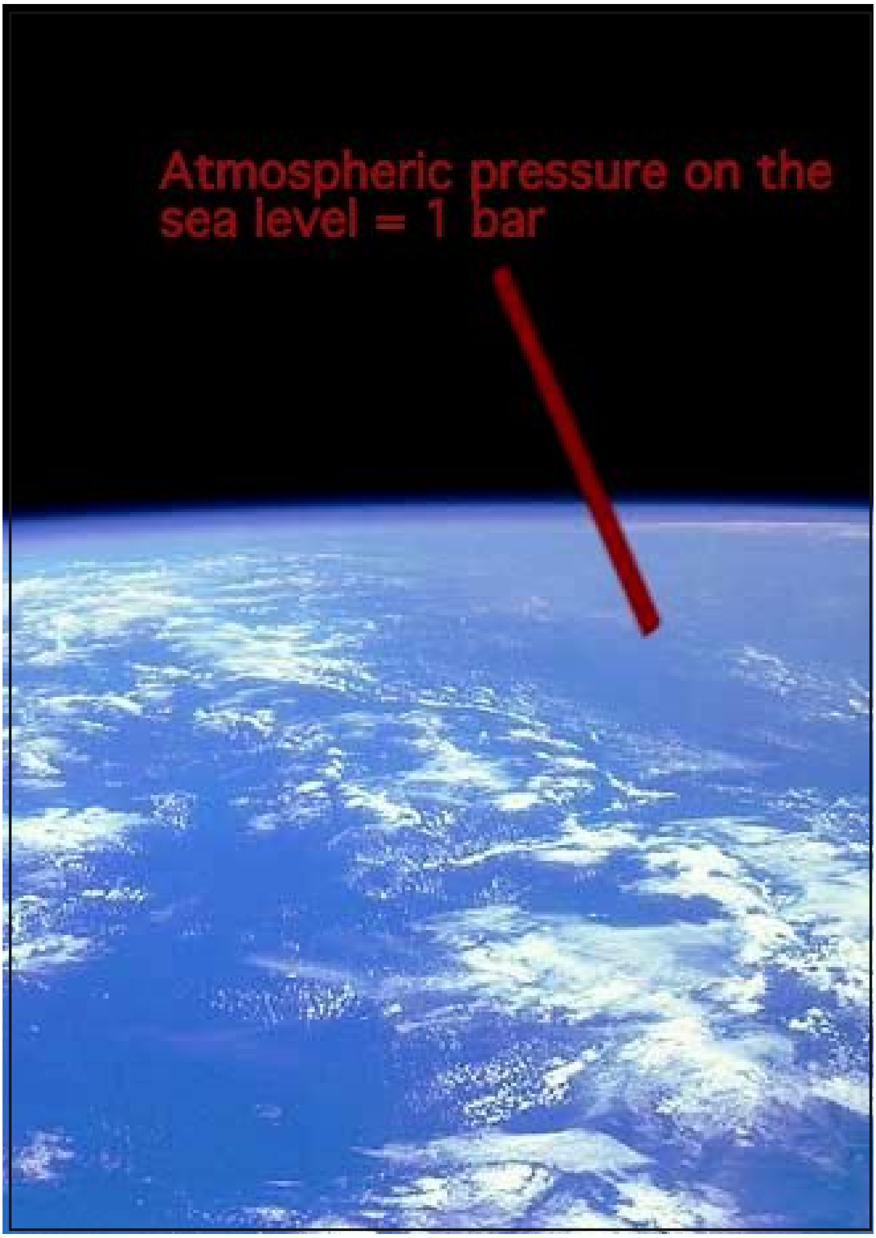
Carbon dioxide is heavier than air, colorless and has an acidic taste. When we have to much CO2 in our lungs we inhale, so we can say that CO2 is a breathing stimulator.



Nitrogen is an inert gas without color, smell or taste. In normal conditions it doesn't affect metabolic processes. It's normal agregate state is gas. All gasses disolve in liquid under pressure. Since it is not used in metabolic process it acummulates in the blood under pressure, and if enough time is not given for the accumulated nitrogen to return to gas in the lungs, then it can cause Decompresion sickness (further explained on page 100).



Pressure



All gasses in the air make an unique atmospheric layer around the Earth, which at the sea level acts under the pressure of 1 bar. The pressure decreases as the altitude increases. The pressure in water is a completely different story.

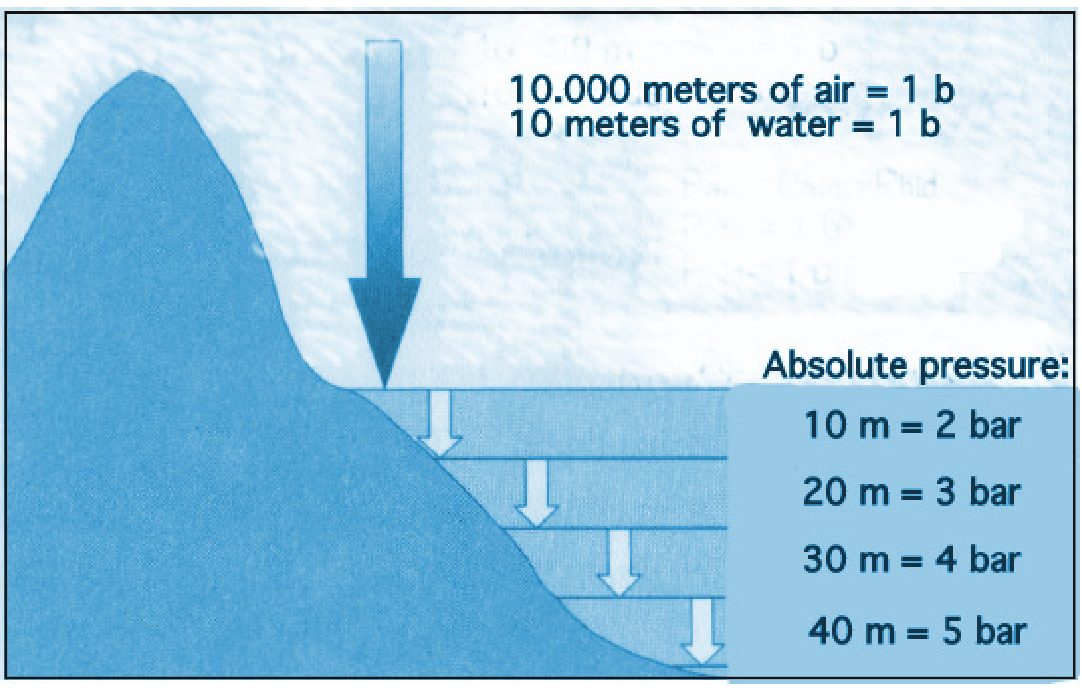
Water Pressure

The pressure of water is called hydrostatic pressure. It rises one bar every 10 meters. On 10 meters it is 1 bar, at 20 meters 2 bars etc. The sum od the pressure of the atmosphere and the hydrostatic pressure gives the absolute pressure that acts on objects in water.

10 meters of salt water + 1 bar of atmospheric pressure= 2 bars

20 meters of salt water + 1 bar of atmospheric pressure= 3 bars etc.

The absolute pressure= (depth/10 +1) bar

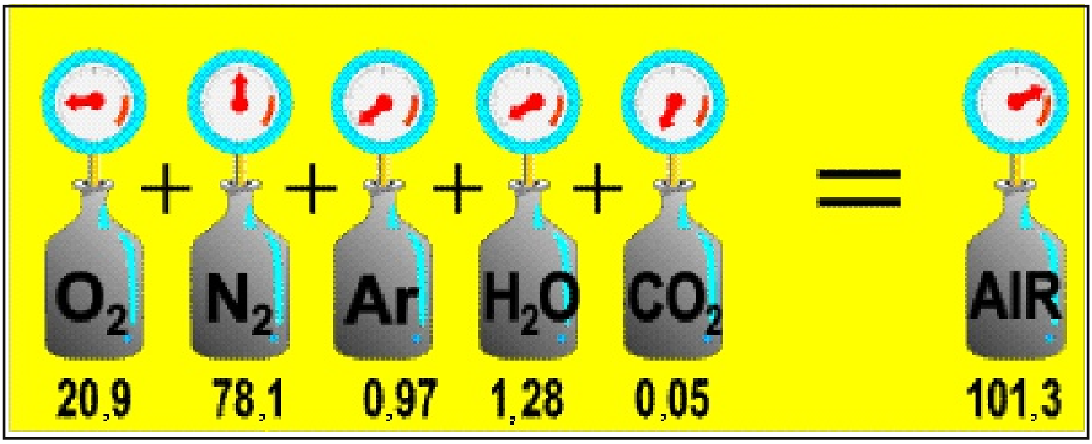


Partial pressure

Dalton’s Law States:

“ The total pressure exerted by a mixture of gases is equal to the sum of the pressures that would be exerted by each of the gases if it alone were present and occupied the total volume”

The pressure of a substance= $p_1+p_2+p_3$. At sea level with a pressure of 1 bar, the partial pressure of the oxygen is 0.21 bar and the partial pressure of nitrogen is 0.78 bar. When we add them up (along with other smaller components of air) we get the total pressure exerted by the mixture we call air.



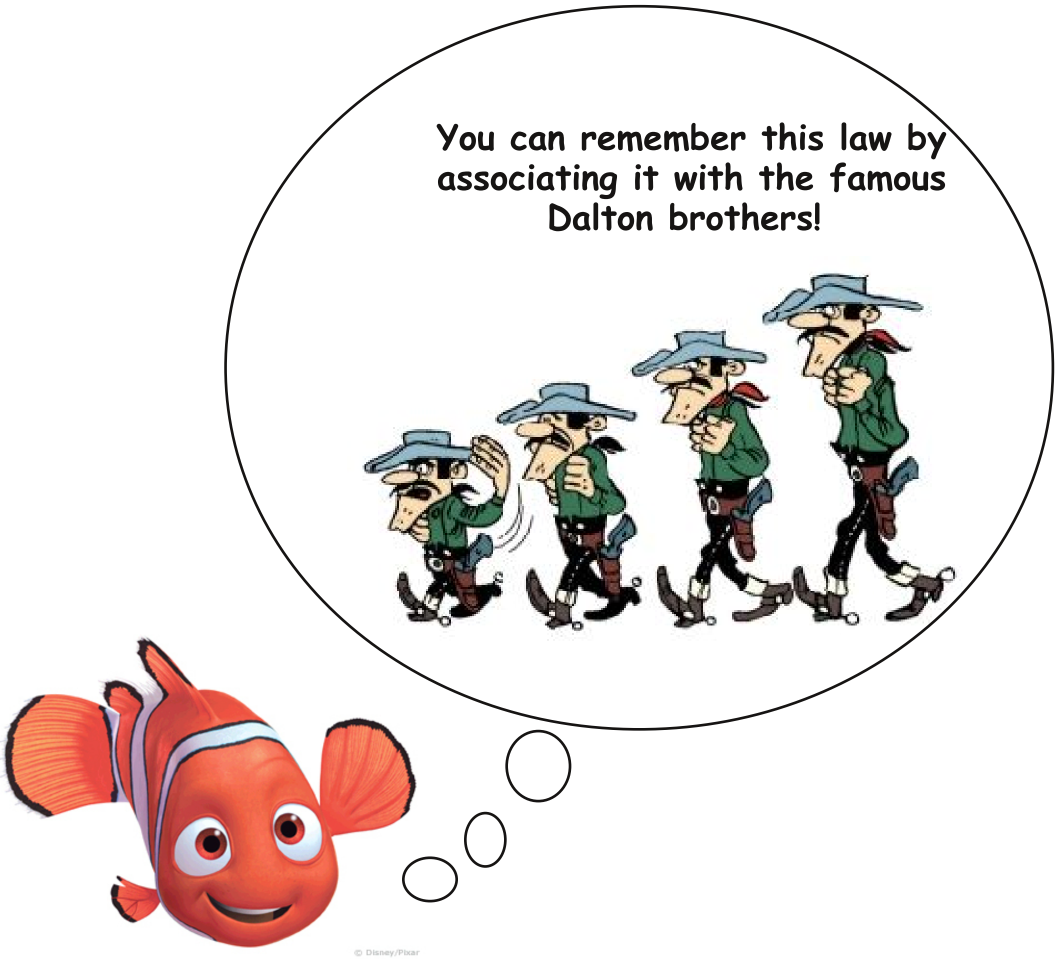
While underwater a diver breathes compressed air under ambient pressure. At a depth of 10 meters, the pressure inside the lungs will be the equivalent of the ambient pressure, 2 bar. Thus, the partial pressures of each of the gases shall increase.

Partial pressure of some gas at some depth = partial pressure of that gas on 1 bar x the absolute pressure on a given depth

Example:

Partial pressures of oxigen and nitrogen on given depths:

1 bar (sea level) - 02 oxygen, 0.8 nitrogen
2 bar (10 meters) - 0.4 oxygen, 1.6 nitrogen
3 bar (20 meters) -0.6 oxygen, 2.4 nitrogen etc



The solubility of gasses in fluids

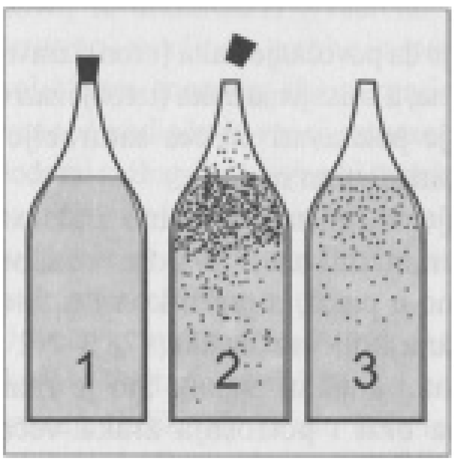
The Henry's law describes the solubility of gasses in fluids:

"Under constant temperature, the amout of gas which dissolves in a volume of liquid is directly proportional to pressure"

That means that that the deeper the diver descends the greater the quantity oxygen and nitrogen passes into the blood stream and the tissues. The increase in the partial pressure of the oxygen causes no problems at the recommended depths for recreational diving. However, the quantity of nitrogen absorbed (which is 4 times greater) can cause serious health problems. This is why divers do decompression stops (stops at one depth according to deco tables which are used to breath out the excessive nitrogen out of the body) and safety stops (3 minutes on three meters should be done on every dive), to release the accumulated nitrogen out of the body.

Different gasses get absorbed at a different rate and same goes with the fluids. Some fluids dissolve gasses more easily. The solubility is inversely proportional to the temperature.

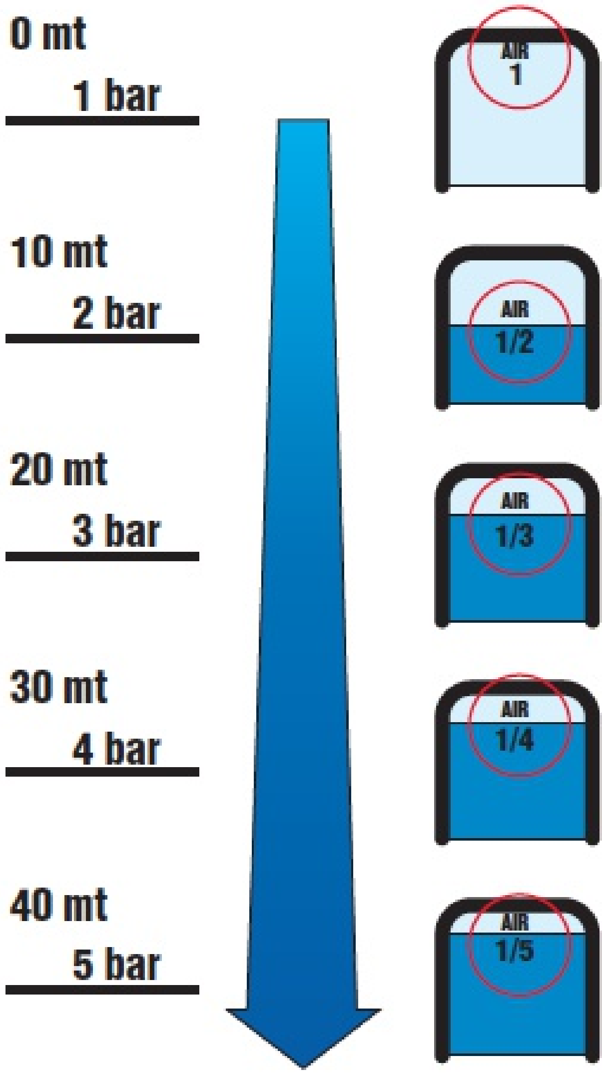
We can explain Hanry's law on a simple case of a soda drink. While the cap is on the bottle, gas (CO_2) is dissolved in the soda, When we take the cap off, the pressure lowers down- that is becomes the same as the atmospheric. As the pressure lowers down the fluid absorbtion powers lower down so the gass is released in a form of bubbles. If we slowly open the cap the bubbles do not form.The same thing happens with the nitrogen dissolved in our body. If we emerge too fast it turns into bubbles causing decompression sickness (see page 100).



Pressure and volume

The Boyle's law explains the relation between the pressure and volume :

"At constant temperature the volume of gas is inversely proportional to the absolute pressure of the gas, while the density of the gas is directly proportional to absolute pressure"



In apnea (breath hold diving) the volume of air in the lungs decreases.

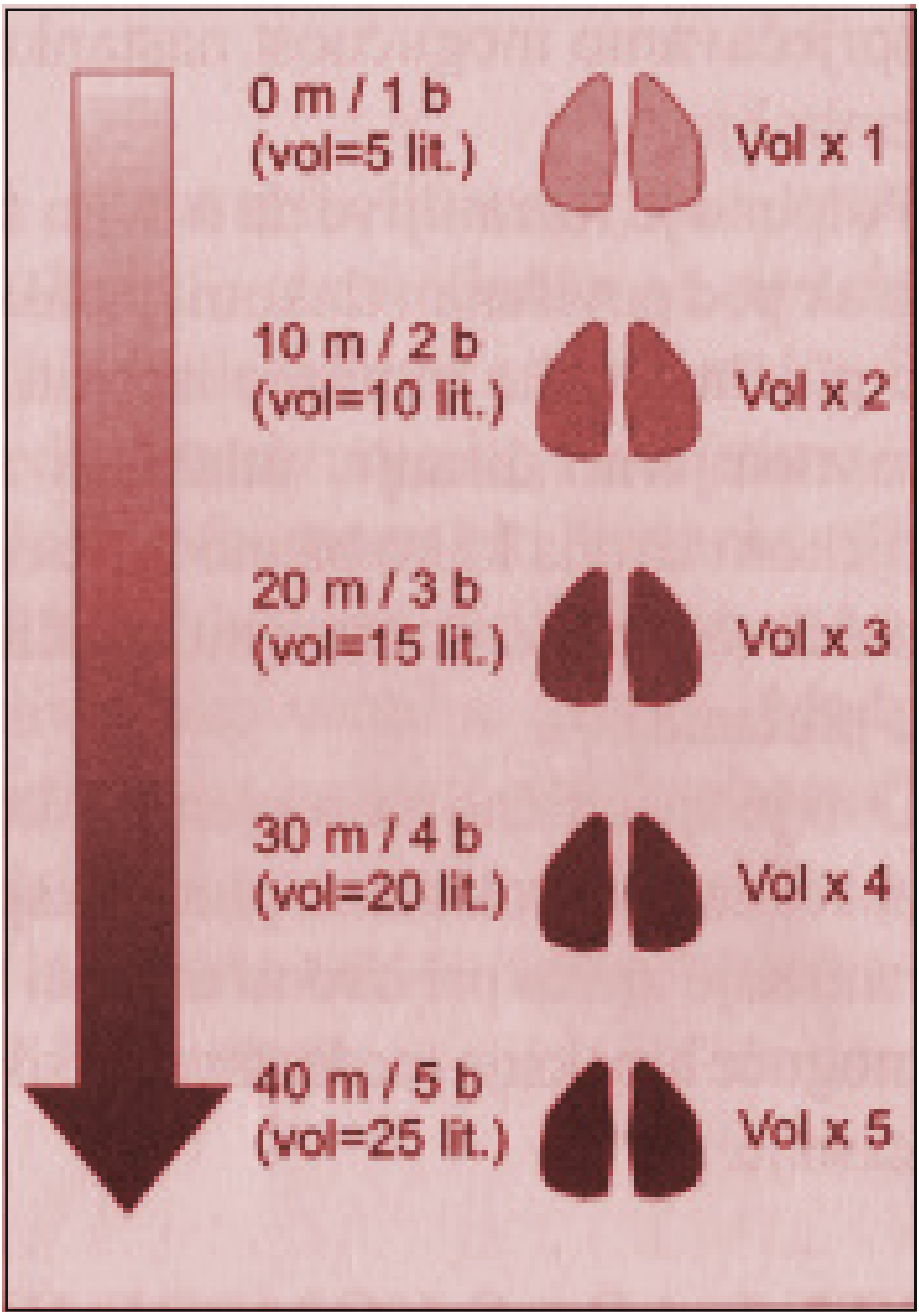
In apnea (breath hold diving) you inhale only once before descent, so if you exhale you release oxygen needed for your survival.

Never breath out in apnea before ascent!

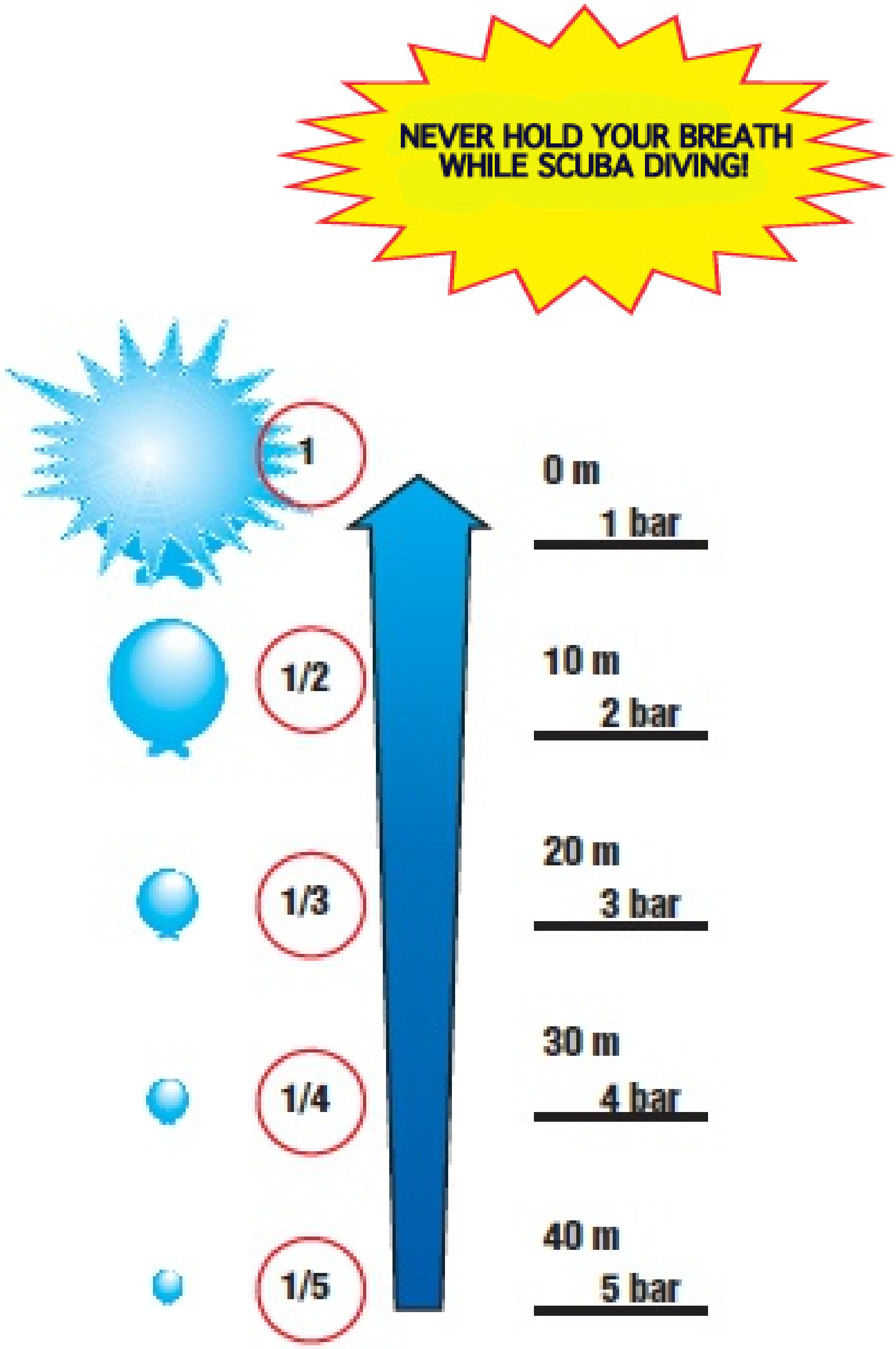
In scuba diving the actual volume and density of inhaled air in lungs changes according to the ambient pressure. Volume is inversely proportional to the pressure, and density is directly proportional to the pressure. If we have a lung capacity of 5 liters, on surface (pressure of 1 bar) with a full breath we inhale 5 liters, but under pressure of 2 bars we inhale 10 liters because of the density of the air. The capacity of the lungs does not change! When we start going towards the surface in a dive, the pressure decreases and thus the volume of the air increases. If we hold breath our lungs can burst. YOU NEED TO BREATHE CONSTANTY DURING SCUBA DIVING!

NEVER HOLD YOUR BREATH WHILE SCUBA DIVING!

Change of volume of air in the lungs while scuba diving:



What happens if we do not breath during scuba diving.
The blue baloon represents the lungs:



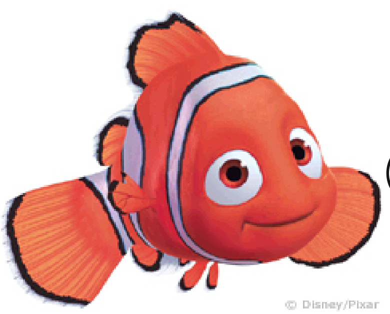
Temperature and pressure

The law which explains the relation between the volume and temperature at a constant volume is Gay-Lussac's law which states:

”The pressure of a gas of fixed mass and fixed volume is directly proportional to the gas's absolute temperature.”

The most obvious application of this law in diving is when filling diving cylinders. Namely, the tanks heat up when filled and thus the pressure is bigger in them. A hot cylinder with 200 bars will have aprox. 180 bars when it cools down.

Always check how many bars (bigger pressure = more air) do you have in your cylinder before you dive. Check this after you get in the water. It is possible that the cylinder cooled off and the pressure reduced, so you will have less air for your dive!



In order to fully understand this topic talk to experienced divers and trainers. COLLABORATE AND COMMUNICATE!