Open Water Diver

Part 5

Other physics laws

5 Other physical laws

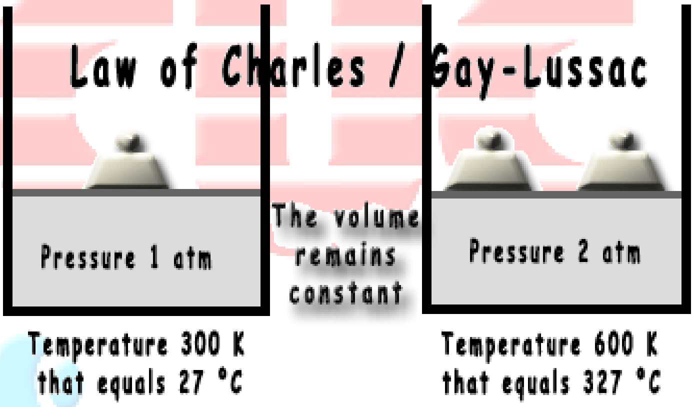
Now we will see 2 physical laws that interest the diver. The first relates the pressure and volume of a gas with its absolute temperature. Although it was Gay-Lussac who related the pressure of a gas with its temperature, which is what matters to us as it affects the air or gases stored in the tank, whose volume does not change. However, it is perhaps best known among divers as Charles's law, so we will refer to it many times as that.

The second is Dalton's Law which explains the partial pressures of gases in a mixture. It is of interest to diving because the different gases that make up the air can affect our body according to their partial pressure, facts that we must know to avoid their incidence.

5.1 Charles & Gay-Lussac's law

It is named after two physicists but it is better known as Charles's Law. Charles related the volume of a gas with its temperature and Gay-Lussac the pressure of a gas with temperature, which together with Boyle's law comes to be the same. We can summarize it like this:

"For the same mass of gas at constant volume, the gas pressure is directly proportional to its absolute temperature".



This phenomenon does not affect our body, as we are homeothermic mammals, that is, we keep a constant temperature inside our body. But we must know its effects since it does affect our equipment, more specifically our tanks.

The direct proportion is at absolute temperature which is measured in degrees Kelvin (K); the conversion of degrees Celsius to Kelvin is adding 273 (rounding up), so 20 ºC are 293 K (20 + 273 = 293). Let's see the implication of this physical law with diving.

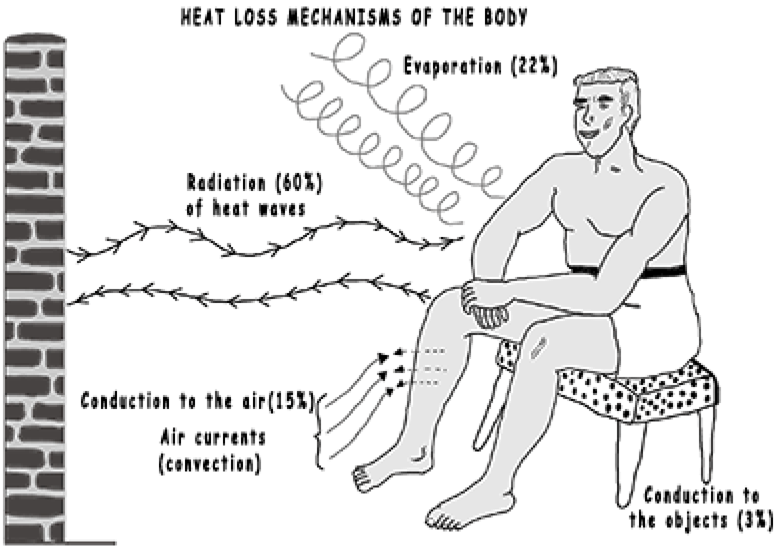
When the tanks are filled up, they heat up because the gas is compressed, so if they are filled to 200 bar, when cooled, they will have a lower pressure. We should not be surprised therefore if when checking the pressure, it gives us a reading lower than 200 bar; it is normal, even if the tanks were filled to 200 bar initially.

For the same reason, we should not put a filled tank in the sunlight, as it heats up and therefore its pressure increases, surpassing the work pressure so that damage to the equipment could occur when the regulator is attached. It is not usual, as there is a margin of safety in the equipment, but it is best to avoid heating the tanks. Do not forget that the interior of a car parked under the sun can reach very high temperatures.

5.2 Thermal aspects

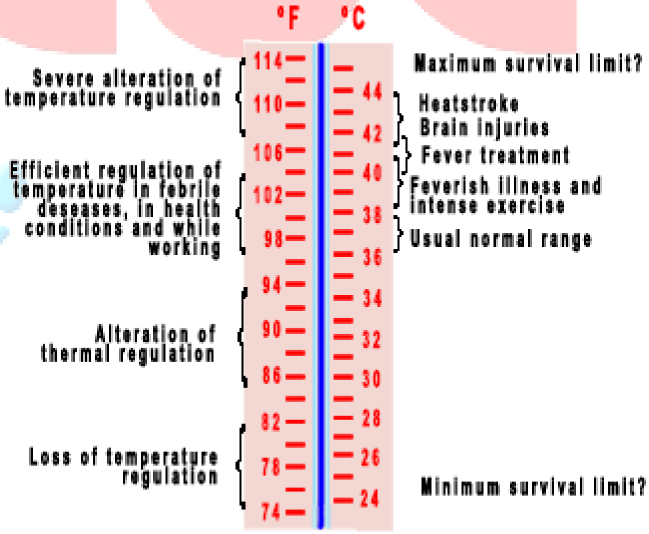
We are going to see some considerations regarding the thermal equilibrium, that is to say, problems derived either by the cold or by the heat, also known as thermal traumatisms. The human being, leisurely, without clothes, in a room without air movements, reaches its neutral thermal environment at 18 ºC (64.4 ºF), but the water is 24 times more thermal conductive than air, so the neutral temperature in the water is reached at about 24 ºC (75.2 ºF). Such water temperature we can only find it in warm areas.

Related with our body, the concept hypothermia indicates a temperature below the normal one and the concept hyperthermia indicates a temperature above the normal one. The so-called normal temperature is the constant temperature inside our body and varies from one individual to another, but for the vast majority, it oscillates between 36 and 37 degrees Celsius (96.8-98.6ºF). The important thing for each person is to keep their internal temperature constant, as the body is very sensitive to any change in temperature, triggering mechanisms to keep it constant (cold or hot feeling).



If the inner temperature tends to decrease (hypothermia), the mechanisms of regulation known as cold feeling are triggered: shivering, muscular movements to produce heat, unpleasant sensation that leads us to seek heat, etc. If that is not enough, as the inner temperature drops, the peripheral blood circulation (hands and feet) is limited, followed by arms and legs too, in order to preserve the temperature of our vital organs (the brain and the inside of the trunk). This can represent a danger because our movements become clumsy and uncoordinated, due to limited blood circulation in arms and legs. The only prevention for us is to ascend to the surface when noticing shivering and recover our thermal equilibrium protecting ourselves with dry clothes (as we warm up). To avoid the cold, we must always use a thermal protection suitable to the temperature of the water in which we are going to dive and always dive with the neck protected (with a hood), since it is one of the areas where we most easily lose heat (together with groin and armpits).

If the inner temperature tends to increase (hyperthermia), the mechanism regulation known as heat feeling is triggered: sweating, breathing acceleration, feeling of fatigue that leads us to a stop of the activity and to look for a cool place, etc. If that is not enough, as our inner temperature increases, we can reach a thermal shock (heat stroke) that can cause a loss of consciousness. Under the water it is rare to suffer a heat stroke, due to its great thermal conductivity, so the precaution consists in not wearing a thermal protection much higher than necessary and if we feel overwhelmed by heat, we must finish the dive and refresh ourselves on the surface. However, the main precaution against hyperthermia, we must have it on the surface, before diving, to prevent the so-called thermodifferential shock that we describe next.



Body temperature in different conditions

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Thermodifferential shock is the same problem we observe in the so-called "stomach crump". It can occur when we undergo a very sudden change in temperature, which can lead to sudden loss of consciousness and even, in severe cases, cardiorespiratory arrest. Such a sudden change in temperature can happen if we are very hot and we dive into the water directly, without prior acclimatization.

To prevent it, the first thing we have to do is not to overprotect us on the boat if it's hot. It is better to finish adjusting the equipment and the suit shortly before the dive. We should not jump to dive directly to the water in warm environments, but rather we should previously wet our wrists, front and back neck and chest, thus avoiding the sudden change in temperature. If we feel very hot, we wait for the refreshing manoeuvres we do to relieve that heat, before the dive.

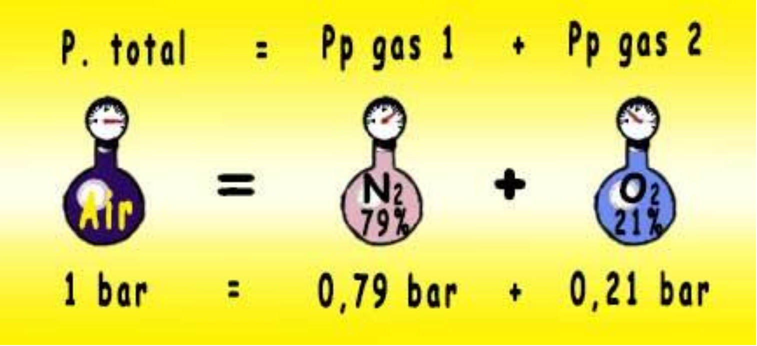
In summary, we must cancel the dive if we feel very cold or are shivering, we must use adequate thermal protection to the temperature of the place and of the water; stop and refresh ourselves if we feel very hot and, very important, we must adapt our body to the water before the dive, wetting our wrists, face, neck and chest if it's hot.

5.3 Air composition – Dalton's law

Air is made up of different gases, of which are of interest for diving nitrogen (N_2), oxygen (O_2) and carbon dioxide (CO_2). There is also argon in a concentration higher than that of CO_2 but we will ignore it because for what it may affect diving, we add it to the concentration of N_2. What we must know is that the air is a mixture of gases and in a mixture, each of the gases exerts its own pressure, called partial pressure, the total pressure being the sum of the partial pressures. That's Dalton's Law:

"In a mixture of gases, the total pressure exerted is equal to the sum of the partial pressures of the individual gases".

In the case of air, we will summarize it in oxygen and nitrogen, which are the main components. We will also talk about carbon dioxide later because it affects us when diving, but its concentration in the air is 0.038%, so its partial pressure is not relevant, but what does affect us it is the variation of concentration, because CO_2 is indeed a metabolic gas.



Oxygen represents almost 21% of the air, so its partial pressure at sea level is 0.21 atm.

Nitrogen represents almost 79% of the air (nitrogen + argon), so its partial pressure at sea level is 0.79 atm.

Hence when we breathe air at 1 atm (at sea level), we are breathing O_2 at 0.21 atm and N_2 at 0.79 atm.

The importance for diving is that each of the gases causes alterations in our body depending on its partial pressure. We are going to call toxicity to such alterations, that is, each one of the gases can get to be toxic depending on its partial pressure.

Oxygen is toxic starting at a pressure of 0.5 bar, which means that it has toxicity problems starting at about 15 m of depth. But let's not worry, since this toxicity also depends on the exposure time, being that time many hours, so our dive will end long before it can affect us. Those safety times diminish when pressure is increased, but to the depths that we descend in recreational diving there is no problem.

Nevertheless, there is a cumulative effect related to those times that disappears when we have not dive for 24 hours, but we must keep it in mind in the case of diving trips, where we can do 2 or more dives a day for several days. As such calculations are out of the knowledge required for a first diving course, it is enough to know for the moment that, in general, we must take a break of at least 24 hours without diving after a maximum of 5 days of diving with successive dives. It usually coincides with diving trips which are mostly one week long, so you actually dive for 5 days. If our dive trip is longer, we must take that 24-hour break after each 5-day dive period.

Toxicity causes from slight damages in the pulmonary tissue to convulsions and death by drowning in exposures to very high pressure, but for your peace of mind, in recreational diving such cases do not happen, as we do not go down so deep. Of course, to avoid minor damage, follow the advice of the maximum 5 days of diving consecutively, if you are going to do several daily dives for several days in a row.

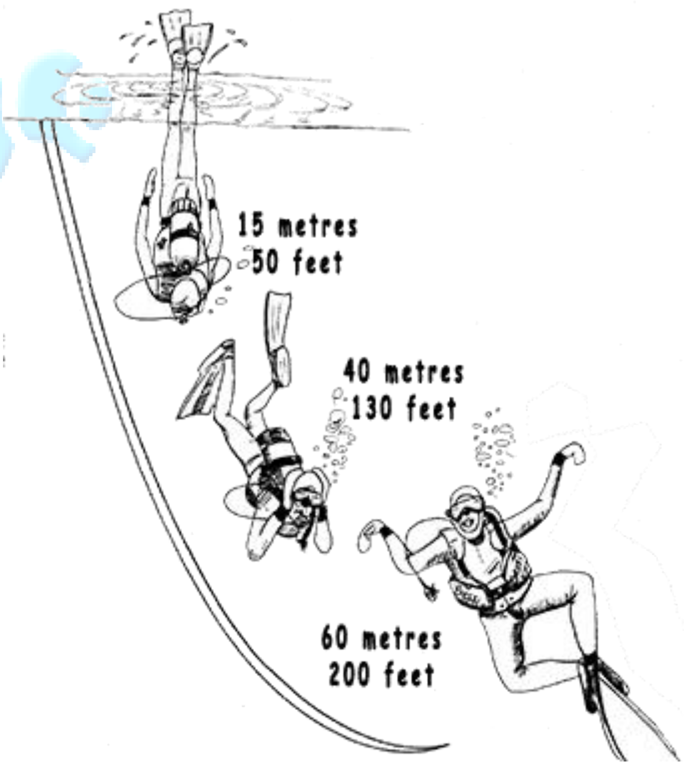
Oxygen causes pulmonary toxicity and neurological toxicity, with pulmonary toxicity starting at 15 meters depth. Depending on the pressure that we breathe and the length of time, the lung tissue can be damaged, so you have to make a 24-hour break without diving after 5 days of successive dives, since in those 24 hours the lung tissue recovers.

The neurological toxicity is much more serious as it causes alterations similar to the great epileptic seizure, so the diver could drown due to loss of the regulator, but it is not to be feared in recreational diving because it appears from 1.6 bar partial pressure of oxygen, with time limits, pressure that it is reached from about 70 meters of depth. While diving with Nitrox, the maximum partial pressure of oxygen is regulated at 1.4 bar for safety.

Nitrogen is toxic at 40 meters and deeper, as the ambient pressure at that depth is 5 atm, the partial pressure of Nitrogen is almost 4 atm (0.79 * 5 = 3.95), which is the reason why in most countries safety rules prohibit descending more than 40 meters deep in recreational diving (another matter is professional diving or specialized diving, as gas mixtures are altered).

Nitrogen toxicity is better known as Nitrogen narcosis, Rapture of the deep or Martini's effect. What happens is that the nitrogen at that high partial pressure affects our nervous system in a similar way to that which alcohol does, so we behave as if we were under the influence of alcohol. Certainly, the situation is dangerous, because we lose the capacity for attention and concentration and therefore, we do not worry about our own safety. The effect disappears without any sequels as we ascend (because pressure becomes lower), so if we observe such symptoms in our buddy (abnormal behaviour that cannot go unnoticed), we must bring him a few metres up, with what all the symptoms will disappear.

Nitrogen narcosis or Rapture of the deep, despite not leaving any trace (no hangover), it is very dangerous because the behaviour of the person becomes erratic and we are underwater, so that an accident or drowning may occur; Even more, to ascend that person, we must go to the same depth he is, so we can be affected ourselves. The only prevention is never to go down over 40 metres deep if we breathe air.



However, the depth up to 40 metres is established because it is starting at this equivalent pressure when we can observe striking and dangerous effects of narcosis, but the narcosis is progressive, beginning its effects, although mild, at a much lower depth. For this reason, it is recommended not to exceed 30 metres depth for safety, as there is a gradual dulling of our mental state as we go deeper, so that our response to any stimulus or need becomes slower, which affects our safety. To the inexperienced diver, ACUC also recommends not diving over 25 metres of depth until you acquire experience or take the ACUC deep diving specialty.

The added problem is that one of the first effects is the loss of self-analysis capacity which causes the diver to be unable to perceive any symptoms as, in general, what he perceives is that he "feels good". Hence its danger and the obligation not to exceed 40 metres of depth in recreational diving.

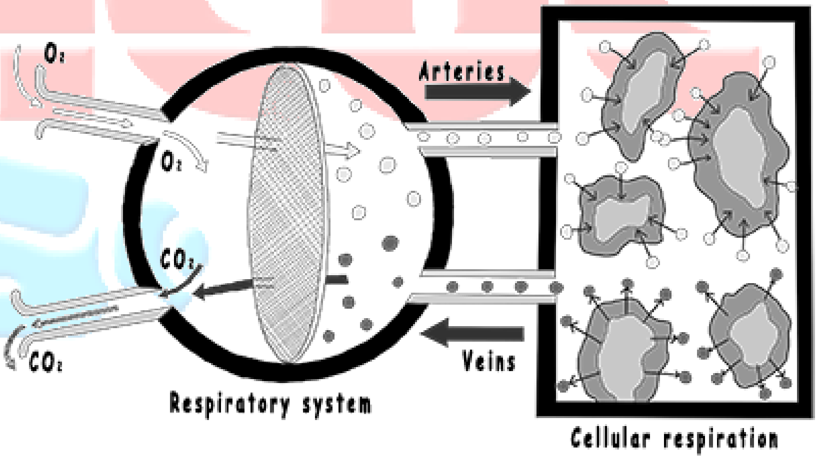
5.4 Breathing and carbon dioxide

Carbon dioxide (CO_2) is another component of the air but it is in such a small amount that it is not contemplated when discussing Dalton's law and partial pressures. However, being in such a small amount does not detract its importance in any way; it has it indeed and a lot. It is sufficient to know that its increase is one of the important factors of climate change (global warming).

Another aspect that we should know is that it is the most important element for breathing regulation in our body. It can be summarized by saying that the spontaneous regulation of our breathing is carried out by our nervous system according to the rate of CO_2 in the blood. If the rate increases, breathing becomes more rapid and intense, if the rate decreases, breathing becomes slower and lighter.

CO_2 is produced by our metabolism: the cells of our body use the oxygen that our blood transports, the chemical reactions that we call metabolism are made inside the cells and residual elements are produced in those chemical reactions, one of them being CO_2. It could be called a waste product and its accumulation would be disastrous for the organism, so a process is necessary for its evacuation. Such a process is breathing. Thus, it can be said that the respiratory function is to supply oxygen to our cells and to evacuate to the outside the carbon dioxide produced by them.

We show you a scheme that graphically represents both pulmonary respiration (to the left) and cellular respiration (to the right). The clear bubbles represent oxygen, which passes through our lung membrane (the alveoli) and the blood transports it through the arterial system to our cells. Oxygen enters the cells, by the metabolism carbon dioxide is produced, represented by the darker bubbles, which leave our cells and the blood transports it through the venous system to our lungs, it goes through the pulmonary membrane and then goes outside through our exhalation.



Diving with scuba equipment we perform what is called reverse breathing, so we must "learn" to condition our breathing so that it is fluid and continuous. Let's explain the "reverse breathing".

We are not aware because breathing is automatic, we do not need to think about breathing, but for air to enter our lungs, a muscular effort is made, both in the thoracic cage and in the diaphragm, to increase the volume of the lungs. Thus, increasing the volume decreases the pressure and therefore the air enters from outside through our respiratory tract. That is the inspiration that, as we see, requires a small effort, even if we are unaware of it. Now, on exhalation, all we do is that both the muscles of our rib cage and our diaphragm return to their resting position, thereby compressing the lungs and forcing the air out through the respiratory tract. That is the exhalation that, as we see, does not require any effort, it is a passive movement.

It is different while diving. In the second stage of the regulator the air is reduced to ambient pressure so that we can breathe, but it arrives trough a hose which keeps it at a higher pressure. We need to make an effort (imperceptible) to open the air inlet valve and from there the air practically floods our lungs. The inspiratory effort is minimal, much less than on the surface. However, when exhaling, we need to permanently overcome the resistance of the exhausting membrane of the regulator. The effort is also imperceptible, but the result that matters is that in our normal breathing outside the water, the inspiratory moment is active and the exhaling one is passive, while diving, the inspiratory moment is almost passive and the exhaling moment is active. That's why it's called reverse breathing.

As we have insisted, we must get used from the beginning to breathe continuously without ever holding our breath (besides for preventing the accident of lung overexpansion that we have already explained to you), because if inadvertently, we make respiratory blockages or do not exhale the air well, it increases the rate of CO_2 in the blood, which increases our breathing rate. We could think that there is no problem as by increasing the breathing rhythm it corrects itself. Usually that is the case, but such increases can later cause an annoying headache and, above all, breathing can be accelerated so much (panting) that it loses efficiency, with the added bonus that **an excess of CO_2 causes a feeling of fear and even panic**, which can be dangerous.

Prevention is to breathe normally by exhaling the air well, something that we will learn to train from the beginning. If we perceive panting, we should not think that we are fatigued, but that we are breathing poorly, so we must stop and pay attention to exhaling the air thoroughly, not to inspiring, which will always be correct, but to exhale thoroughly. After two or three breaths exhaling thoroughly panting should disappear.

The same procedure is what we should do if at some point we feel fear. We will see that there is no reason to feel fear while diving, so that sensation usually indicates poor breathing. The fear will disappear as soon as we stop and do several breaths taking care to exhale the air well (exhaling thoroughly). Remember that there is no need to worry about inspiration, as it will be automatic and to the same extent that we have exhaled.

To summarize, let's repeat that we should breathe normally during the whole dive without ever holding our breath. If we notice rapid or panting breathing, we stop and take several breaths exhaling thoroughly and we should do the same if we feel fear during the dive.

5.5 Anoxic syncope (also known as Shallow Water Blackout)

There is another event related to CO_2 also, which we think is important to explain since, although diving with scuba we will never be exposed to this accident, we do expose ourselves by diving in apnoea, that is without scuba and holding our breath. We must know it since it is an accident that causes many deaths a year by drowning.

When we hold our breath, CO_2 accumulates in our blood, since the alveolar air is not exchanged with the outside. This accumulation causes us to feel the need to breathe (or a sensation of suffocation), since it is the rate of CO_2 that regulates our breathing. That feeling causes us the urge to go up and breathe.

By practicing apnoea, it is possible to increase the time before feeling that need to breathe, but, in addition, there is a "trick" that also allows us to prolong the time, although we will see that it is a "trick" with sometimes deadly results and it should not to be used. The trick consists of a previous hyperventilation, that is, we take very deep breaths just before the dive, thereby greatly reducing the remaining CO_2 in our lungs, which gives us more time in the dive, because we start the dive with very little CO_2 and it will take longer for us to accumulate enough of it to give us the feeling of "need to breathe".

The problem arises because by staying longer, we are also consuming alveolar oxygen for a longer time, which obviously will reduce its partial pressure. For oxygen diffusion through the alveolar wall to occur, a minimal pressure is necessary. If consumed to that minimum partial pressure, oxygen stops diffusing and a state known as "anoxia" occurs. Our brain reacts immediately to anoxia (lack of oxygen), producing an immediate loss of consciousness. This situation is called "anoxic syncope."

Holding our breath is a voluntary act so, if we suffer an anoxic syncope, when we lose consciousness, we stop voluntarily holding our breath and as we are submerged, we breathe water, causing drowning. This is the cause of the majority of drownings which occur among free divers.

The name is anoxic syncope, but it is also known as shallow water blackout, surface water syncope and, in some places, as 7-meter syncope. It is known that way because the accident is triggered during the ascent, which is when we lose depth and, therefore as the air in our lungs expands again, it gains volume and therefore the oxygen loses partial pressure, that is why it almost always happens in the ascent, shortly before reaching the surface.

The simplest way to avoid this accident is by not hyperventilating before diving. Thus, we will feel the need to breathe before we have consumed so much oxygen that this syncope appears on the ascent. We will certainly spend less time underwater, holding our breath, but in return we will avoid this fatal accident. Remember that the feeling of needing to breathe is not caused by the lack of oxygen, but by the excess of carbon dioxide. Of course, there should always be someone on the surface, watching, to help us out in case of problems.

5.5 Summary

In this topic we have talked about Charles's law, thermal aspects and air composition (Dalton's law). We will see how fast and easy all the information provided can be summarized.

- Never leave the tanks under the sun, in the trunk of the car parked under the sun or in any heat source.
- Take the appropriate actions to avoid being cold. Diving is for enjoyment. If we feel cold while diving, we stop and get on the boat or go ashore to warm up.
- Do not dive suddenly if we are hot. Previously, acclimatize by wetting our face, neck and chest with water.
- In the case of two or more daily dives during several days, do not dive more than 5 days in a row, introducing a 24-hour break to eliminate the cumulative effect of oxygen.
- Do not descend more than 40 meters deep to prevent narcosis. Preferably only dive to a maximum depth of 25 metres; going deeper requires a specialty course and a lot of experience.
- Breathe normally, never holding your breath and paying attention to exhaling correctly. If we notice agitated breathing or feeling of fear, stop and take several breaths, exhaling the air thoroughly.
- If we practice apnoea diving, do not hyperventilate prior to the dive and always have a safety person at the surface.