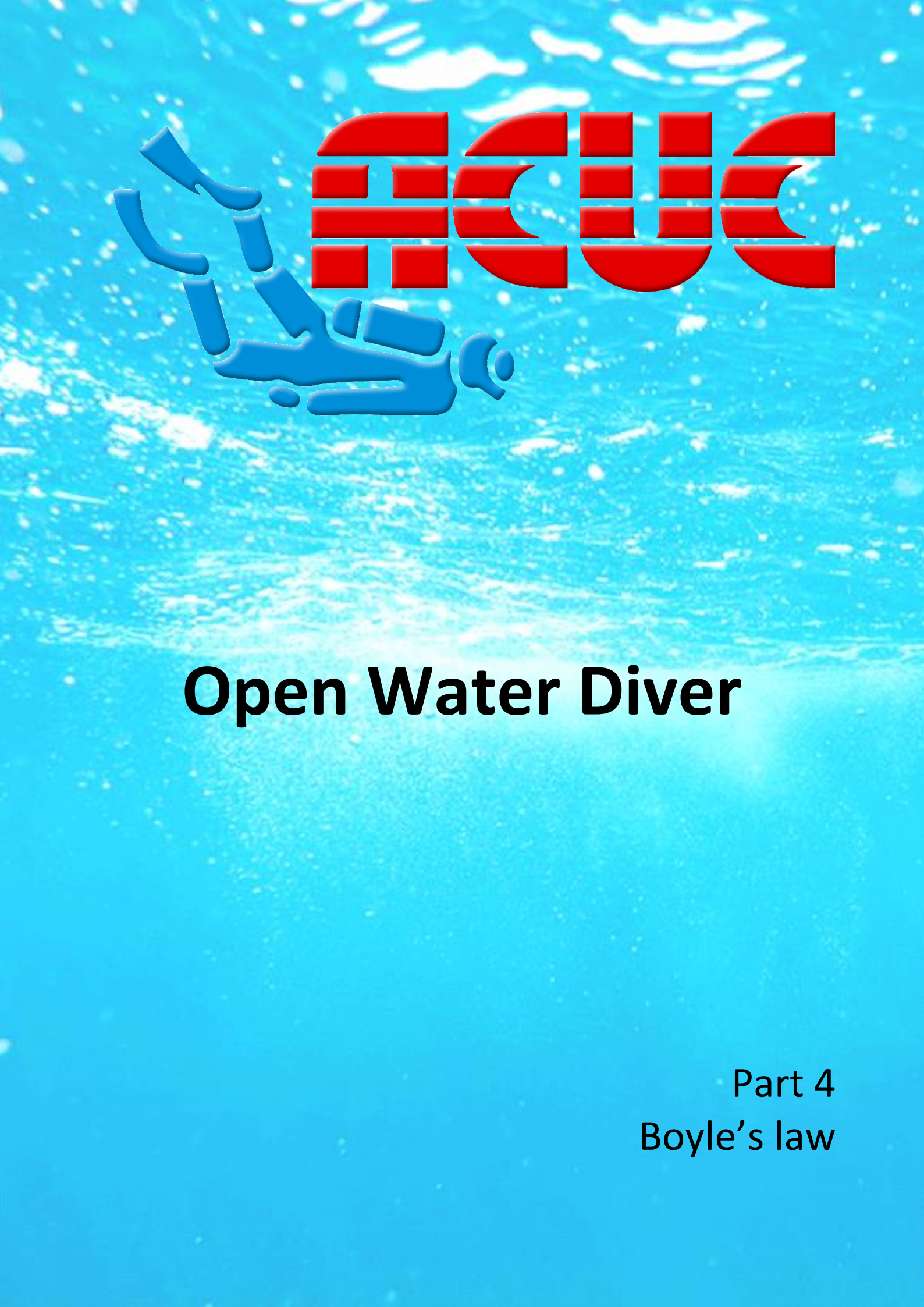


Open Water Diver

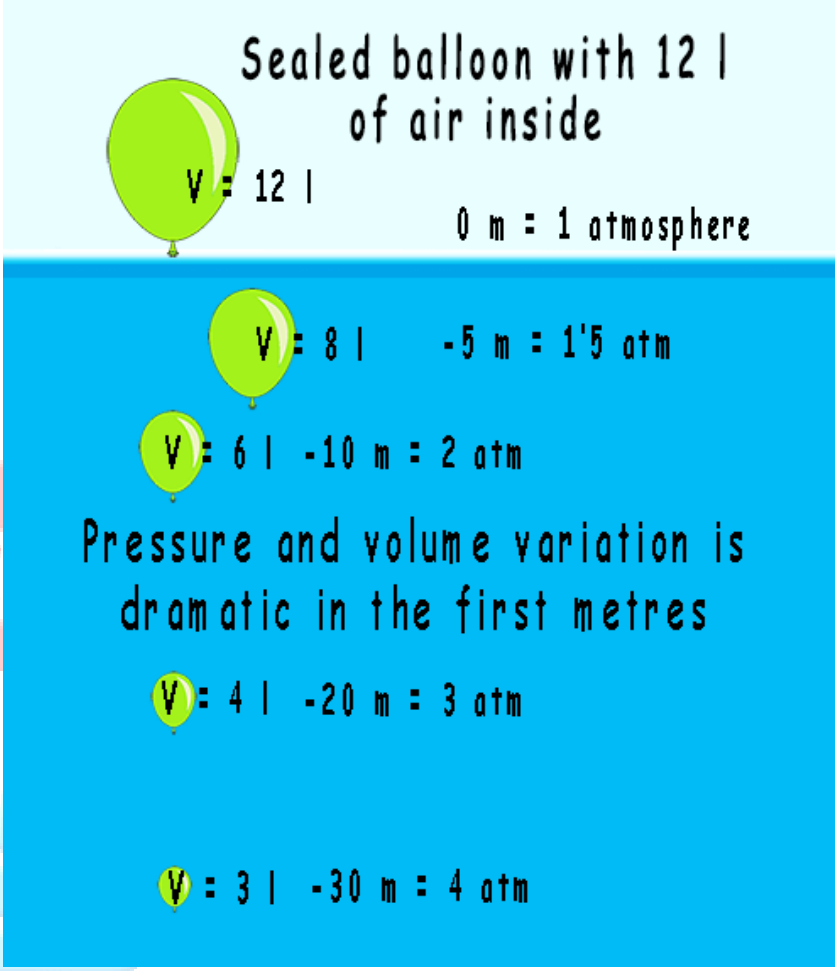
Part 4

Boyle’s law

4 Boyle-Mariotte's Law – Associated barotraumatisms

Better known as the Boyle's Law, it relates the pressure of a gas with the volume it occupies. It tells us that for the same gas mass at constant temperature, the gas pressure is inversely proportional to the volume it occupies. That is, if the pressure increases to double, the volume decreases by half and vice versa.

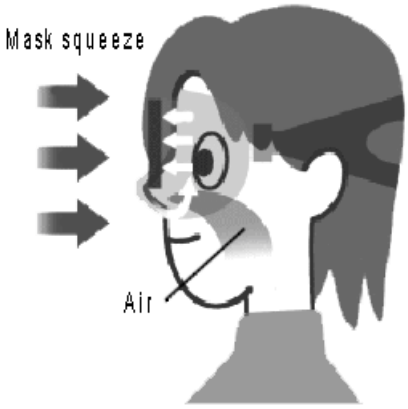
If we look at the illustration, very similar to the one we saw in the previous section, we see a closed balloon with 12 litres of air inside, so we already have a constant mass of gas. If we take that balloon to 10 metres deep, its volume will be reduced to 6 litres; if we take it to 20 metres deep it will reduce its volume to 4 litres and if we take it to 30 metres deep the volume will be reduced to 3 litres. If we release the balloon it will ascend, increasing its volume as it rises and will reach the surface with its original volume of 12 litres. The huge difference in volume in the first metres is noteworthy. We have shown the balloon at 5 metres deep and we can see that in only 5 metres the volume is reduced from 12 litres to 8 litres and the pressure increases by 50%, from 1 atm to 1.5 atm.



We have also talked about pressure, atmospheric pressure, pressure relative to water and absolute pressure or ambient pressure, explaining that the pressure variation is more abrupt the closer we are to the surface. This aspect must be kept in mind as the problems that we may have related to the pressure variation will be all the more important the closer we are to the surface.

This physical phenomenon is of enormous importance for the diver, because it affects all the gaseous spaces involved, inside and outside our body, let's see one by one how it affects us, the prevention of the accident that it can cause, leaving the most important for the end.

4.1 Mask

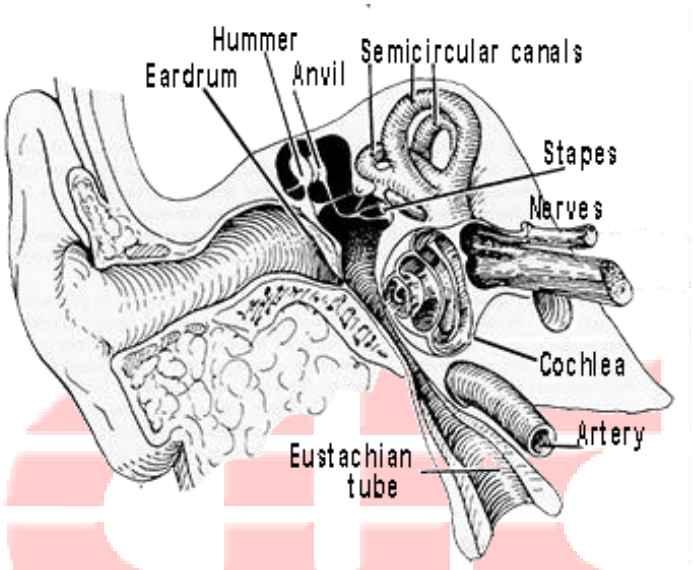


By putting on the mask we create a sealed volume of air inside. As we go down, the pressure increases then the volume decreases, so the mask is crushed against the face. This phenomenon creates a depression inside the mask that, if it persists or if it is intense, can even cause the breakage of some capillary (conjunctivitis), noticeable by the red spots that appear in the whites of the eyes. Of course, we cannot allow this to happen and that is the reason why **the mask must cover the nose**.

As we descend, we breathe a little bit through the nose (a very thin blow is enough) and the balance of pressures is restored. We will notice that the mask loosens and it is comfortable again. Whenever we increase depth the pressure increases, then we have to blow some air through the nose. As we ascend the pressure decreases but no action is necessary on our part, as the air, when increasing its volume, escapes by the edges of the mask.

This precaution should always be remembered, but especially when starting the descent, as the pressure variation is very striking in the first metres. This accident, although it does not imply vital danger, can leave us very upset and without being able to dive while it heals.

4.2 Ears



It is possible you have experienced earache when diving into the sea or even into a pool; or you've heard the repeated comment that ears hurt when diving. It's true, but let's see the reason and the solution. Remember we dive for enjoyment, not for getting hurt in anyway.

The eardrum is the membrane where hit the sound waves in its outside so it vibrates and that vibration is transmitted to our nervous system, which interprets it. That is the mechanism of hearing. However, for it to vibrate correctly it does not have to be subjected to any tension, that is the reason why behind the eardrum there is also an aerial chamber: the Eustachian tube, communicated with our nostrils, so that the pressure on both sides of the eardrum is always the same, which allows no tension on any of its sides (exterior and interior). Nevertheless, such communication is not very wide, because it is hampered by the narrowness of the canal and by cilia and mucus, which serve as a filter and protect against infections. It does not matter, because the pressure changes in our environment are minimal, so the ears have plenty of time to equalize.

However, when we climb or descend a mountain pass in the car or when we travel by plane, these pressure differences are accelerated, so it is very likely that you have experienced weird sensations in the ears in those situations, because a pressure difference between one side of the membrane and another happens, which deforms it, limits our hearing and even causes pain if the deformation is more pronounced. These inconveniences usually disappear with a simple yawn or jaw movements, because when moving the jaw, the opening of the Eustachian Tube is involved and the balance of pressures is restored.

When we submerge, the pressure increases very sharply, especially in the first metres; As the communication of the Eustachian tube is not so fast, there is no time for the pressure to be compensated with our breathing, so that the eardrum bulges inward, causing pain. If we persist, the accident of rupture or fissure of the eardrum (very painful) could happen. We must not even allow pain to appear so, in order to force compensation, at the minimum discomfort we stop the descent, ascend a few centimetres and, with maxillary movements, we try to compensate. Most often it is not enough, as the pressure differences in the water are too important, so we have the resource of the so-called Manoeuvre of Valsalva.

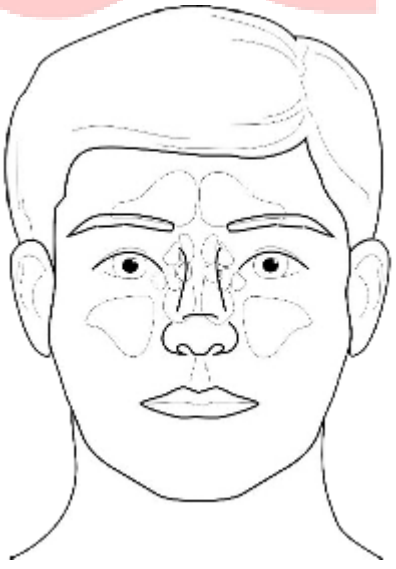
It consists of holding your nose with your fingers and keeping your nose pinched we try to blow **gently** through it. Obviously, as we have it blocked with the fingers, no air comes out, which increases the pressure in the nostrils, forcing the opening of the Eustachian tube and thus restoring the pressure balance. We will notice the "plop" and the feeling of relief in the ears.

We have to do these manoeuvres as soon as we start the dive, to prevent any discomfort. We will see that it is necessary very often in the first metres but then, at more depth, it is barely necessary. The variation of pressure is very rough in the first metres, but this variation rate softens as we go down.

Although more unlikely, we must also know that the feeling of vertigo is possible, both in the descent and in the ascent, because the ears can compensate at different speeds. The difference in pressure between one ear and the other is what causes the sensation of vertigo. Our action should be to stop, preferably holding on to something firm and to fix our gaze on something firm. As soon as the pressures are balanced, the vertigo disappears.

4.3 Paranasal sinuses

They are cavities that we have in the skull on both sides of the nostrils communicated with our airways, but we do not need manoeuvres to compensate the pressures, as they balance very well by themselves; however, there may be exceptions to this claim. If we suffer from a cold, the increase in mucus can cause communication difficulties of the sinuses with the respiratory tract, which prevents them from being compensated and a strong pain happens in the affected sinus area. The pain can be over the eyes (frontal sinuses) or under the eyes (maxillary sinuses), on one or both sides of the face.



The same, but with greater certainty, can happen if we suffer from sinusitis, as sinusitis is precisely an inflammation of these mucous membranes. A pain occurs, usually as a sharp stab and we have no solution, the only thing we can do is to cancel the dive; in either case, we should not force the compensation of the sinuses. If we insist, it could even cause some capillary breakage, besides being very painful. If this happens remember: cancel the dive immediately. There are no consequences if we do not insist and it will not stop us from diving permanently; simply, until that cold or sinusitis crisis is over, we will not be able to dive.

We must not take anticongestives to dive. That is the medicine which is prescribed in cases of cold, nasal congestion or sinusitis. The anticongestives reduce mucous secretions so they can allow compensation of ears and sinuses, which allows us to dive, but in a short time they lose their effect, so that it can produce a "rebound effect", secreting so much mucus that it does not allow the compensation during ascent, so we will ascend between strong pains and possible injuries in sinuses and ears. If we take in anticongestives we should not dive.

4.4 Teeth

Although it is a very rare and infrequent event, it could be that, in case of caries or a poorly made filling, a cavity is formed inside the tooth that causes problems if its communication with the oral cavity is difficult, as it does not give time to the compression and expansion of gases in our ascents and descents.

There is no solution to balance, so in case of dental pain when descending, we must cancel the dive and go to the dentist to solve our problem. There is also no safety problem except the pain experienced, but as we said before, this event is very unlikely. There is also no problem to dive with inserts or implants.

4.5 Bowels

Even inside our intestines there may be gaseous volumes that will undergo compression and expansion according to Boyle's Law. Usually there is no problem, since the gas is in the bowels, when we descend, it is compressed and when ascend it expands, but to the volume that it had before, so there are no consequences. The problem may arise if we eat flatulent foods or drinks with bubbles before the dive. In this case, gases can be produced during the dive, being at more pressure, therefore compressed. When ascending, these gases expand and can cause abdominal pain and cramping.

The accident is not serious, since it is cured like any colic, with hydration and diet, but it is painful and very annoying or unpleasant, so we should avoid it. As a precaution, we will not take meals that cause flatulence at least 24 hours before diving, nor copious meals nor drink bubble drinks before the dive. We do not indicate the types of food, as such type of foods are different from one person to other. Each person should avoid those foods that they know cause him flatulence.

4.6 Pulmonary overexpansion

We leave for the end the description of this accident related to Boyle's Law, because it is by far the most serious, although also the easiest to avoid, so that it remains fresh in the student's memory and so you can review it as many times you need easily, going directly to the end of this chapter.

We already know that we need to breathe the air at the same pressure that we are at. The air enters our lungs at higher pressure while diving, but there is no problem because our lungs are subjected to the same pressure. As long as we maintain normal breathing, without ever holding our breath, everything goes well. If we ascend the air expands into our lungs, but as we are breathing, it comes out through our breath without any consequence.

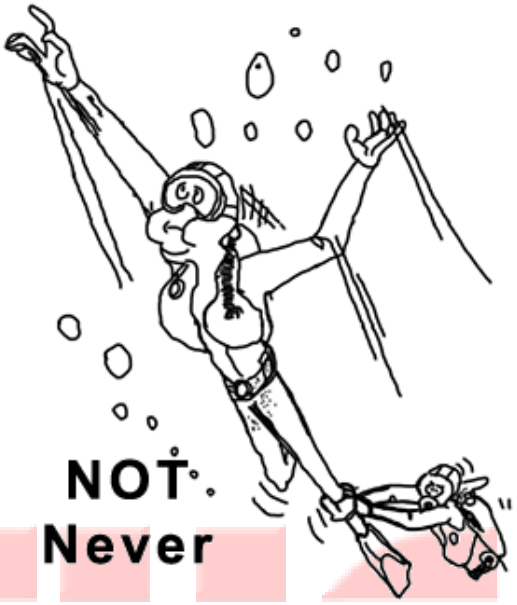
Another very different thing happens if we hold our breath during the ascent. When we dive without breathing equipment, nothing happens, because the air is taken on the surface, we descend, then the air compresses and when we ascend, it expands, but to its initial volume, as we have not breathed anything underwater. When diving with breathing equipment these things change, as we breathe air at higher pressure, so if we hold our breath, as we ascend the air inside our lungs expands (Boyle's Law) and the surplus cannot come out because we have blocked our breath.

The gas in its expansion causes lung expansion beyond its tolerance, causing damage to the lung tissues and leakage of air bubbles to our arteries forming embolisms, and this is a really serious accident, so serious, that it is often deadly. To give us an idea, many of the exercises and practices that are performed in the water in a diving course, are designed to condition the student to prevent this accident.

There is only one way to prevent this serious accident and it is **never to hold your breath**. As we see it is very simple to avoid it, as we have a breathing apparatus in our mouth and what we have to do is to

breathe normally, so we will be free of this danger. We should not take the regulator out of our mouth in an ascent. Even if we have made such an accumulation of mistakes that we have run out of air, going up with the regulator in the mouth forces us to keep it open, making it easier to expel a row of bubbles as we ascend, thus avoiding this accident.

However, we need to know it, to be conscious of its serious consequences and to recognize situations in which this accident could happen in order to train our response. For example, for whatever problem, we run out of air supply during the dive, so we can no longer ascend by breathing normally, another example is the breath blocking reflex due to being submerged; another can be a panic attack that makes us go to the surface holding our breath. Well, enough with scaring things and let's calm down.



That is the main reason why it is mandatory to take a diving course to practice this activity. No dive centre in the world will allow you to dive with them or hire equipment, if you do not show your certification card as a diver, issued by a recognized Organization, in this case ACUC. These diving courses are designed to teach you how to prevent this and other accidents.

First of all, we must never dive with equipment in poor condition. If the equipment is cared and maintained it is very unlikely that it will fail while diving. Nevertheless, as nothing is impossible, you are always taught to dive with an additional source of air, for safety. In addition, you are taught that you never have to dive alone (buddy system), so your buddy can give you his second regulator so you can breathe from his tank as you both ascend slowly to the surface, you are also taught to ask for air to your buddy and to change regulators under the water, with what the problem of the improbable failure of the air equipment is solved. You are learning this right now, but you will also reinforce it in the practical part of the course.

We also insist and your instructor will insist too, that you always have to keep a normal breathing and **never hold your breath**. With this information and the water exercises, you will be conditioned to never hold your breath. The other example that we indicate it is the case of panic attack. This situation is prevented with practical water exercises, instilling confidence and safety to prevent its appearance. In any case, if the ascent is made looking up and expelling a thread of bubbles during our ascent, there will be no problem, because the air expands into our lungs, but goes out without causing any injury and although we do not breathe, we have not blocked the expiration. As we see, everything can be summarized to **never hold your breath**.

There is a procedure to perform what is called an emergency ascent, also known as "free ascent." If despite all the recommendations received, for some reason we were underwater in a situation of "no air", you can make an ascent at controlled speed, permanently ejecting a small row of bubbles through the mouth and looking towards the surface. The air in our lungs expands, but since we are expelling it while we go up, there is no lung overexpansion and then the accident does not occur. The "free escape" is not free of risks, so we should only train it when we already have experience. If there would be any problem with the air, what is really safe is to use the alternative air source of our buddy.

Another source of lung overexpansion accident is having given air to someone who descends to our depth but making a descent in apnoea, for instance a friend or family member who is following us from the surface. By wanting to do "a favour" allowing him to breathe from our equipment so he can be a little bit longer underwater, we are supplying him with pressurized air, so when he goes up holding his breath, as is natural and instinctive, he will suffer this terrible accident. Therefore, **we will never give air to any person**

who is in apnoea. We cannot give air to a non-diver indeed, since he probably does not even know this problem, but neither to a certified diver who knows it or to any other person even informing him about this problem, as the instinct in apnoea is to hold the breath.

The severity of the lung over-expansion accident is accentuated by the sudden onset of symptoms, which greatly limits the time for treatment. First aid is essential and the greatest severity, in addition to being conditioned by the importance of the injuries, is also conditioned by the time spent accessing a hospital, preferably with a hyperbaric chamber. The treatment if this accident occurs is the urgent transfer of the victim to a hospital with a hyperbaric chamber, maintaining vital signs and performing cardiac massage and artificial respiration (CPR) if necessary, giving the victim pure oxygen to breathe and having him drink plenty of water if he is conscious.

4.7 Summary

Although it seems a lot of information, if we summarize everything related to Boyle's Law, we will see how easy it is to remember it:

- Blow some air through the nose during the descent and from time to time during the dive, to prevent the squeezing of the mask; we will notice that this also increases comfort.
- Equalize your ears without allowing the pain to appear, start to equalize them at the beginning of the descent. The compensation is done with swallowing manoeuvres, maxillary movements or the Valsalva manoeuvre.
- If there is any pain in the paranasal sinuses leave the dive. We must not insist.
- Do not take anticongestives before diving.
- If there is dental pain leave the dive. We already know that we must go to the dentist.
- Avoid flatulent foods and bubble drinks before diving.
- You must never give air to another person diving in apnoea.
- Always expel a small row of bubbles through your mouth when you do not have the regulator in it, and above all:

NEVER HOLD YOUR BREATH