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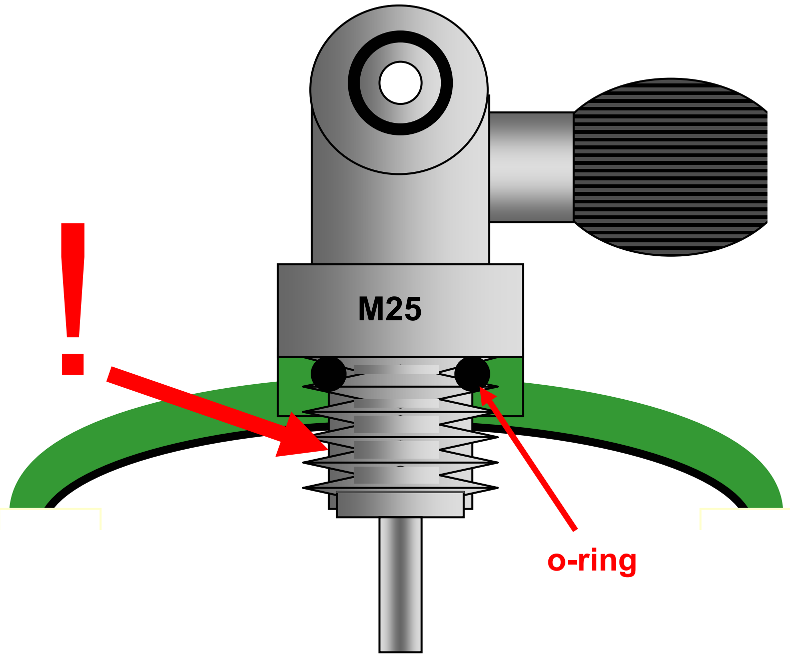
The risk of putting the wrong valve in a cylinder has become bigger with the introduction of the M25x2 thread. With a clear norm for the construction, the M25x2 has solved the problems with the different constructions in different countries, but the connection is on first sight very similar to the ¾ gas. All newer European cylinders are fitted with the M25x2 thread.

You can not screw a ¾ gas valve in an M25x2 cylinder, but the other way around will work. After the first 4 or 5 turns the resistance is increasing. For the professional this would be enough of a warning that there is a mix-up, but the uninformed might force the valve into the cylinder, damaging the threads on the valve. The damaged valve can not hold 200 bar pressure and will "explode" out of the cylinder during or shortly after filling. This creates an extremely dangerous situation. This especially happens when divers are buying a new valve for their old cylinder. Cylinders can last for decades and there are still many in use with the old ¾ gas connection. Trying to find a dive center that has already experienced an incident with an M25x2 – ¾ gas mix-up might be easier than you think.

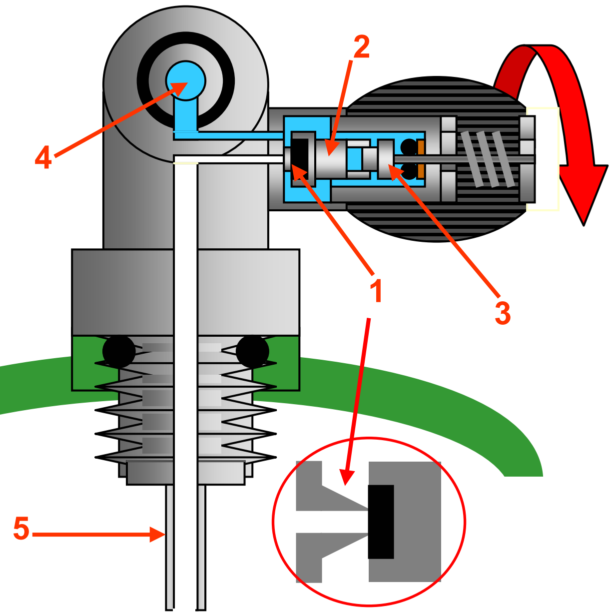


You will find an M25x2 (sometimes just M25) marking on all newer cylinders and valves. If you do not find any indication of the thread, it is not an M25 connection and special attention is required. Another point of attention with older cylinders is that they may not be rated for 200 bars. In France you can still find the once popular bi-huit – a double 8 liter cylinder – which was rated for a pressure around 170 bars.

Newer cylinders are no problem, but as diving cylinders may serve divers for decades, you might get confronted with older ones. You need to pay special attention if you do not find an M25 marking.

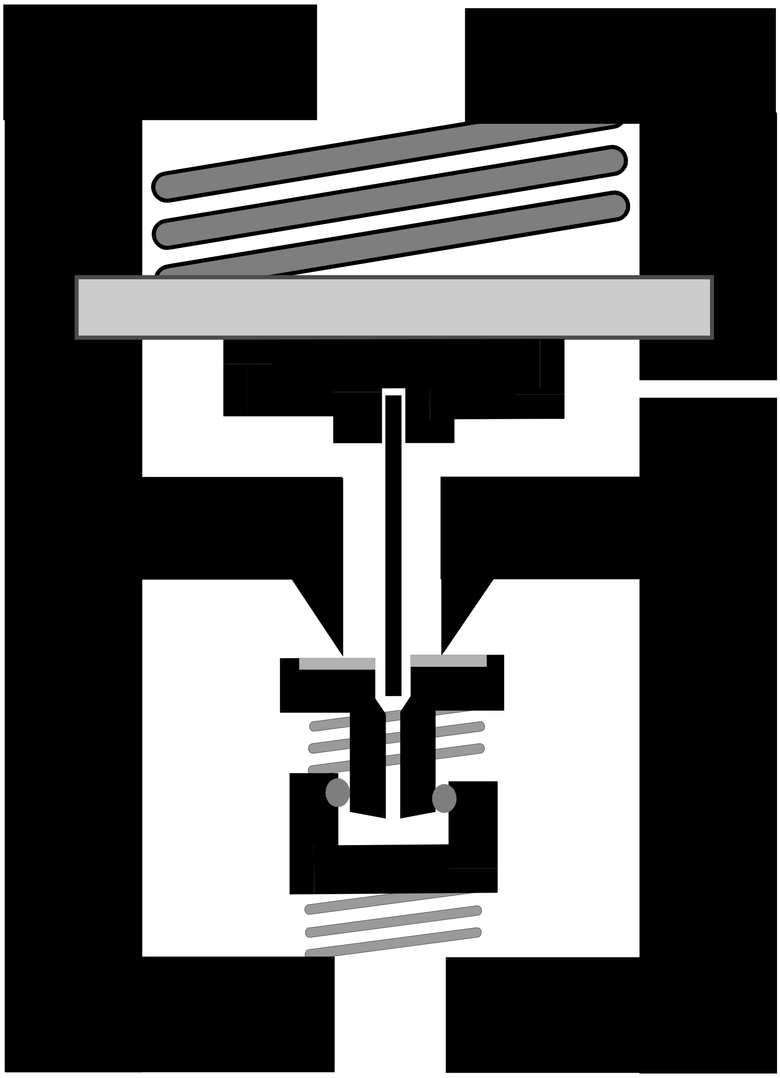
Most cylinder valves are simple open and close valves and by adding or removing an insert, they can be used with either a DIN or international (yoke) regulator (Fig. 1 – number 4).

Fig. 1



The pressure in the cylinder is blocked with the valve (the soft part) which is closing on the seat (the sharp part – Fig. 1 – number 1). The valve is part of the "lower spindle" (number 2), which is turned in and out with the help of a sort of "screwdriver", called the "upper spindle" (number 3), which is connected to the knob.

If a closed valve with no regulator attached gets under water, the entire blue marked area will fill with water. A burst of air will only clear part of the water, because a big part is located "behind" the air flow. This will leave a residue of salt, dirt and minerals in the valve, which will interfere with smooth operation.



On first sight the functioning of a balanced membrane first stage is more complicated, but when we keep the information from the introduction to first stages in mind, the concept is easy to understand.

The balanced membrane first stage is almost the same as the non-balanced membrane first stage, but rather than the conical shaped valve, we find a normal seat (the sharp edge) and valve (the soft coating on top of the small piston).

The entrance of high pressure and the connection for the second stage and other intermediate pressure hoses are found on the same location as in the non-balanced membrane first stage.

The functioning of a first stage of this type is based on the fact that equal opposite forces annul each other.

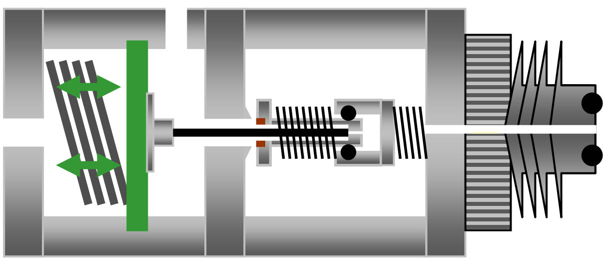
The little piston has a passage to an intermediate pressure chamber (or balancing chamber). The first part of the bore is big enough for the needle to enter, but the second part has a smaller diameter to prevent the needle from falling through the piston. The diameter of the intermediate pressure chamber is the same as the diameter of the passage between the high pressure chamber and the intermediate pressure chamber. This means that also the part of the small piston sticking out around the seat has the same surface above and under. This brings us the following complete formula for a balanced membrane first stage (assuming that the diameter of the passage between the high pressure chamber and the intermediate pressure chamber is $8mm^2$ and that the part of the small piston sticking out around the seat has a surface of $10mm^2$):

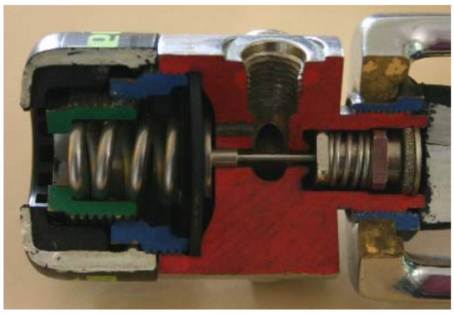
$$MP.500mm^2 = P_{spring}.500mm^2 + P_{ambient}.500mm^2 + P_{middle}.8mm^2 - P_{middle}.8mm^2 + P_{cylinder}.10mm^2 - P_{cylinder}.10mm^2$$

As an identical + and – annul each other and after deleting identical surface areas, the formula ends up the same as for the balanced piston first stage:

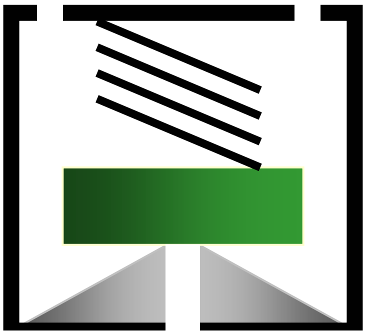
$$MP.\cancel{500mm^2} = P_{spring}.\cancel{500mm^2} + P_{ambient}.\cancel{500mm^2} + \cancel{P_{middle}.8mm^2 - P_{middle}.8mm^2 + P_{cylinder}.10mm^2 - P_{cylinder}.10mm^2}$$

$$MP_{\text{(intermediate pressure)}} = P_{spring} + P_{ambient}$$

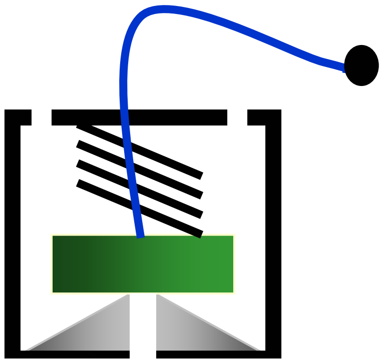




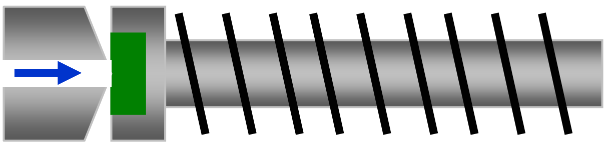
The Traditional Second Stage



The basis of the traditional second stage is a spring loaded valve such as we find on a BCD as an overpressure relief valve. The function of such a valve on a BCD is to prevent rupture of the bladder in case an inflator is stuck or a diver over inflates the BCD. You could say that the construction of the valve is done in a way that if other technical elements or the user fails, the BCD is still safe. One could also say, fail-safe. In a second stage, the valve serves the same purpose. If there is a technical problem in the first stage, the construction of the second stage will keep the regulator safe. Also here this is called fail-safe.

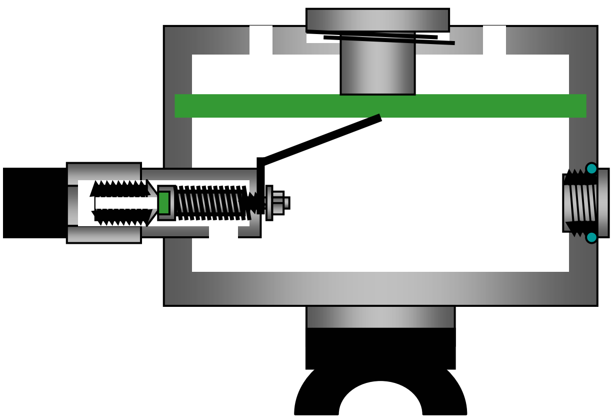


An overpressure relief valve of a BCD is often equipped with a cord that allows the diver to use the valve do dump air from the BCD manually. The lever in a second stage is essentially the same. It is not a cord, but also a mechanism the diver manipulates in order to open the valve. Only tilting the valve (as it would when a lever would be connected to the middle of the seat and moved to the side) would not open the valve enough to allow the flow needed for the inhalation of the diver. This is why we find a mechanism that is lifting the entire valve from the seat. To do this, most valves are inserted in the end of a small piston and movement is created by the lever pulling at this small piston.



The intermediate pressure from the first stage arrives at the seat (the blue arrow). The valve mounted in the small piston is pushed by the spring to keep the second stage closed. This means that the force of the spring (combined with the ambient pressure in the second stage) needs to be strong enough to withstand the intermediate pressure. Assuming an intermediate pressure of 10 bar, the spring needs to be rather strong. The idea is that the spring is just a little bit stronger than needed to close the intermediate pressure valve. All extra force will make itself noticeable in additional breathing resistance, because more force is needed to pull the valve free from the seat.

This explains the changes in breathing resistance when using a non-balanced first stage. The spring in the second stage is adapted to the highest pressure expected from the first stage. The intermediate pressure will change with the variations of cylinder pressure, but the spring in the second stage will keep the same force. The difference is noticed in the force needed to pull the valve from the seat (against the force of the spring) and the breathing resistance (or at least the cracking pressure) will increase.

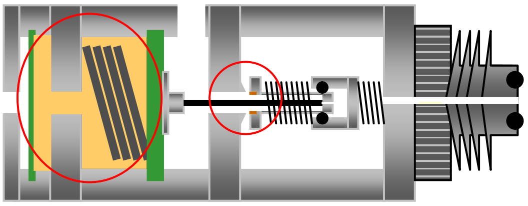


When the diver inhales, the membrane is pulled inward and the lever is pushed down, which because of the shape of the lever pulls the small piston away from the seat. The lever can move all the way down in the second stage, resulting in a maximum opening between the seat and the valve.

A diver manipulating the purge button can not push the lever completely down. The construction of modern purge buttons only allow to press the purge button down for a few millimeters – just enough to create the mild flow needed to purge the regulator or the clear it of water. Old second stages did not yet have a restriction on the purge button.

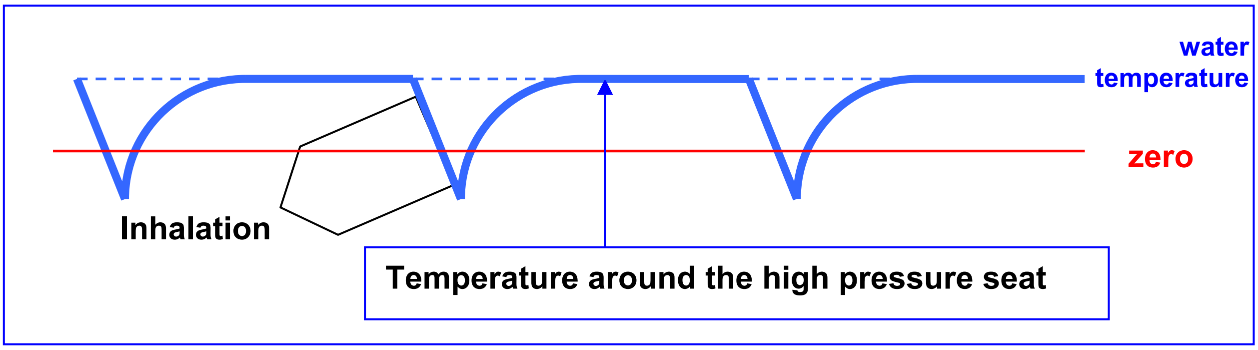
Regulator Freezing

When diving in cold water, ice in the regulator may cause a free-flow. To create ice, two elements are needed: temperatures below zero and water. If one of the two is missing, a regulator will not freeze. It is very unlikely that a first stage will freeze. Cold temperatures are created at the location where the pressure drops. In the first stage this is the high pressure seat. No matter which type of regulator we take, membrane or piston, balanced or non-balanced, at the location where the temperature drops when the diver inhales, there is normally no water.



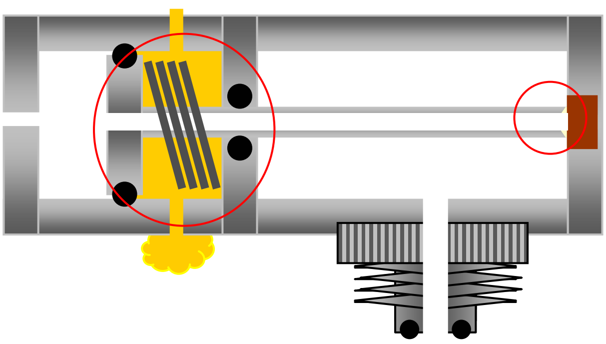
If there is water coming to the location of the high pressure seat, this is coming from the cylinder. This is one of the reasons to prevent water from entering the cylinder as is explained in the first chapter on cylinders and valves. Moist air entering the first stage can accumulate water around the high pressure seat, which can become ice if the temperatures go below zero and can prevent the valve from sealing on the seat. For the diver this means that the inside of the cylinder needs to be dry before the cold diving season starts.

Some first stages are equipped with features to prevent icing. Most of these do not really work, because the added isolation is far away from the actual problem. Only at the high pressure seat, the temperature drops below zero. The first stage is built of metal (a good heat conductor) and the regulator is immersed is water with a temperature above zero (we do not dive in ice). When the diver inhales, the temperature around the high pressure seat drops below zero (which is no problem as long as the air coming from the cylinder is dry), but thanks to the positive temperature of the surrounding water, it will warm up again before the diver takes the next breath.



Isolation around the intermediate pressure spring can serve to keep minerals and salt out of the ambient pressure chamber, but it does not help a lot to prevent the regulator from freezing up. Rather than adding this sort of features, a diver should make sure that the cylinder is completely dry on the inside and is filled by a reputable filling station with excellent filtering and filling procedures.

At some point in time, divers made it a habit to fill the wet chamber of piston first stages with silicone grease, but this created the opposite effect. Rather than keeping sand and dirt out of the first stage, the silicone trapped it inside the ambient pressure chamber. Every time the piston moves, silicone is pushed out of the holes in the first stage and water (with salt and dirt) is pulled in. The sand, dirt and salt stick to the silicone and create a mix of silicone and dirt which is not really good for the first stage.



It was also rather annoying that small quantities of silicone came out of the holes when the first stage was put under pressure, creating a greasy, slippery first stage.

Testing a Regulator in the Field

Sometimes a diver has a doubt if a regulator is functioning properly. To make a choice if the regulator is still in order and safe to make a dive, a small test was developed. This test can be applied to regulators of all makes, even if the diver does not have data available such as the exact intermediate pressure for the specific regulator. The test can only be used on "correct" regulators, meaning that the second stage and the octopus are of the same brand, or at least compatible with respect to the intermediate pressure.

There are 5 steps to be completed and before you get started you need a full cylinder and a bucket of water.

1. Connecting the regulator to a closed cylinder and checking air integrity.
2. Opening the cylinder and checking condition of o-rings, intermediate pressure valves and high pressure valve.
3. Checking the condition of the second stage.
4. Checking the intermediate pressure.
5. Checking the flow.

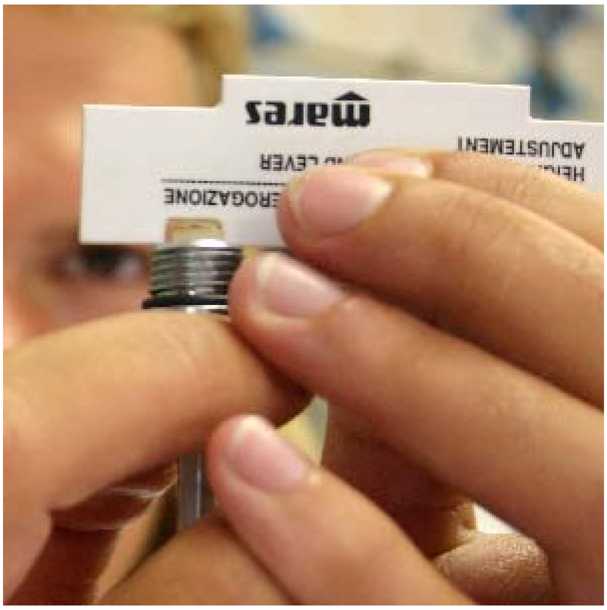
Step 1

In the first step the regulator is connected to the cylinder valve. The valve should not be opened. We now try to breath gently from the second stage (this has to be done gently, otherwise we risk air passing trough the exhalation valve, which would interfere with a correct diagnose). If the regulator is equipped with an alternate air source, the same procedure should be applied to that mouthpiece.

If no air comes out of the mouthpiece(s), the first step is completed. If air comes, we need to find the location of the leak. The first thing we should keep in mind that the air coming out of the mouthpiece, can come from a leak at many different locations. It does not necessarily come from a leak in the second stage we are trying to inhale from. A technician thinks of a regulator in terms of: high pressure chamber, intermediate pressure chamber and ambient pressure chamber. Theoretically seen, the air coming out of the second stage mouthpiece can come from a leak in any of these areas.

It is unlikely that a primary second stage and the alternate air source both get a leak on the same day. If we inhale from the primary second stage and air comes and then from the alternate air source and no air comes, then it is likely that the leak is located in the ambient pressure chamber (the housing of the second stage) of the primary second stage. If we can inhale air from both mouthpieces, then it is likely that the leak is located in either the intermediate pressure or high pressure chamber.

The *high pressure chamber* (as a definition for the use of this test) is the area form the location where the high pressure breathing gas from the cylinder is entering the first stage, up to the high pressure seat and it also includes all what is connected to that area (such as an SPG). With a closed cylinder, the passage between the high pressure chamber and the intermediate pressure chamber is open, due to the lack of cylinder pressure and therefore the lack of intermediate pressure to close the high pressure seat against the force of the spring and the ambient pressure. Leaks in the high pressure chamber are normally very small – too small to be detected in step 1, but this is not a problem, because step 2 will show any leak in that area.



The movable orifice (with the seat) is put in the manufacturer specified position. The technician either knows how many turns he needs to put it in position, or uses an instrument to measure the correct position.

For many second stages it is required to cut of the slack of the exhalation valve once you have it in place, otherwise the part sticking inside the second stage could interfere with membrane movement.

For some parts it is required to add some nut-lock on the threads before assembling the part. This is done to prevent that the part loosens due to vibrations or manipulations by the diver when using the equipment.

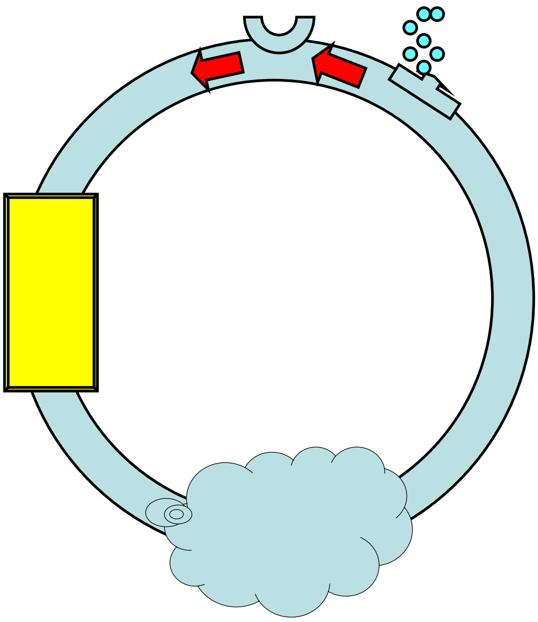
During the assembly, all o-rings need to be greased with silicone grease (or in case of a regulator for Nitrox, oxygen compatible lubrication). Too much silicone is not good for the regulator. We need just enough lubrication to allow the o-rings to glide in their place. A greased o-ring should be shiny with grease only.

Alternative SCUBA Options

When diving with air, at the surface we inhale 21 percent oxygen. When using open system scuba (a regulator), at the surface we exhale 17 percent of the oxygen unused. The same would apply to Enriched Air. When diving with EANx36, at the surface, we exhale 32 percent of the oxygen unused. When depth increases, the percentage of oxygen used decreases when the effort of the diver stays the same. A diver breathing air (21 percent oxygen) at a depth of 30 meters (4 bars) will exhale 20 percent of the oxygen unused. With the same effort, the diver will use the same quantity of oxygen molecules. At 30 meters depth the density of the gas in the lungs is four times higher, meaning that the same percentage (21 percent) represents four times as many oxygen molecules in numbers. Increasing the number of oxygen molecules present, does not increase the amount of oxygen used in the metabolism. The quantity of unused oxygen increases with depth and with an increased percentage inhaled.

Depth	O_2 inhaled	O_2 exhaled	CO_2 exhaled	O_2 inhaled	O_2 exhaled	CO_2 exhaled
Surface	21%	17%	4%	36%	32%	4%
10 meters	21%	19%	2%	36%	34%	2%
30 meters	21%	20%	1%	36%	35%	1%

This means that when diving with open system, we "waste" a lot of unused oxygen. Long before the development of open system scuba, military divers were already using rebreathers, which make use of the exhaled oxygen by recycling the exhaled breathing gas (removing the CO_2) and using it again to make more efficient use of the available oxygen. In the nineties, rebreathers have become an option for recreational divers. Before that they were mainly used by the army.



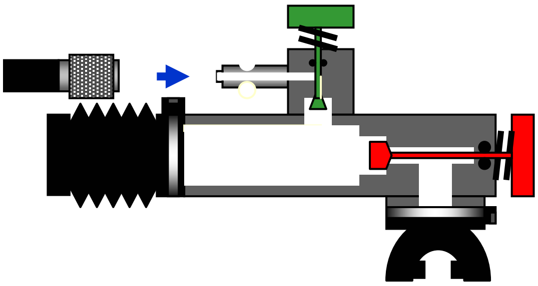
All rebreathers share some common features. All have a breathing circuit with valves, which direct the breathing gas to always pass trough the circuit in the same direction (the circle and the red arrows). All have a mouthpiece that can be closed to prevent water from getting into the circuit when the mouthpiece is taken out of the mouth.

All rebreathers have a flexible part in the circuit, called the "counter lung", which increases in size when the diver exhales and decreases in size when the diver inhales. This means that the sum of the counter lung volume and the volume of the lung of the diver is always the same and that the buoyancy of the diver is not affected by breathing. Exhaling to descend does not work anymore.

Because there is a flexible part, the rebreather is affected by Boyle's law, increasing and decreasing the volume when changing depth. To prevent a rupture of the circuit on ascent, all rebreathers are equipped with an overpressure relief valve. The spring in the valve defines the maximum pressure in the circuit. This means that all rebreathers, regardless of type, model and make, release bubbles on ascent.

The last common part for all rebreathers is a canister with soda-lime. The soda-lime is a chemical which binds the CO_2, thus removing it out of the exhaled breathing gas. Each pellet of soda-lime can bind with a certain number of CO_2 molecules. As we have seen in the table indicating the percentage of inhaled and exhaled breathing gas, the number of CO_2 molecules (not the percentage) stays the same regardless of depth (provided the level of activity of the diver stays the same). This means that a quantity of soda-lime which will be enough for three hours at the surface will also be enough for three hours at a depth of 30 meters.

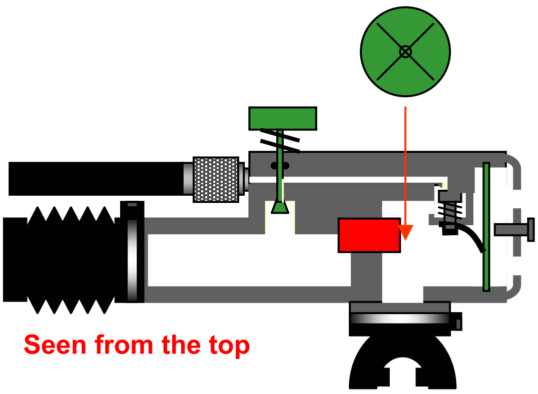
Inflators



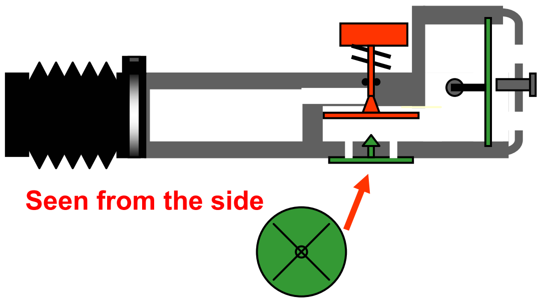
The inflator allows the diver to use air from the cylinder to inflate the Buoyancy Control Device (BCD). The inflator hose is connected to the first stage in one of the free intermediate pressure ports and has a quick connector at the other end to be connected to the BCD (and/or dry suit) inflator.

The inflator is rather simple compared to a regulator, but the design might make it harder to have access to all the o-rings and other parts.

Just like with regulators, flow is an important quality factor for an inflator. A diver who is confronted with a lack of buoyancy at greater depth will want to be able to establish neutral buoyancy without too much delay. This is the main reason why it is not recommended to attach any signaling devices between the inflator hose and inflator, as some models can reduce the performance of the inflator by more than 50 percent.



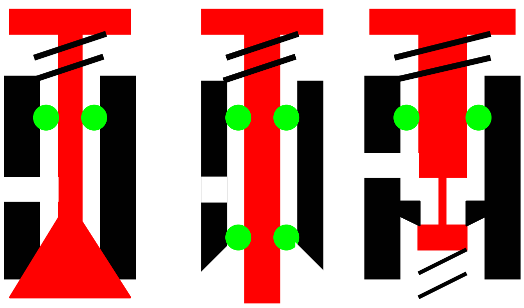
The aspect of flow is especially important when we dive with a combined inflator/regulator. In that case, a second stage is built in the same housing with the inflator, allowing the diver to inflate and deflate the BCD and to breathe from the same mouthpiece. There are no parts which are not discussed up to now. The second stage has a normal membrane and lever and is equipped with a normal intermediate pressure valve and seat. The inflator has the same mechanisms as a normal inflator. The only added feature is that all this aspects are combined in the same housing.



The air supply for a second stage and an inflator can not be adequately handled via a normal inflator hose. This is why you will find them to be equipped with an oversized quick connector.

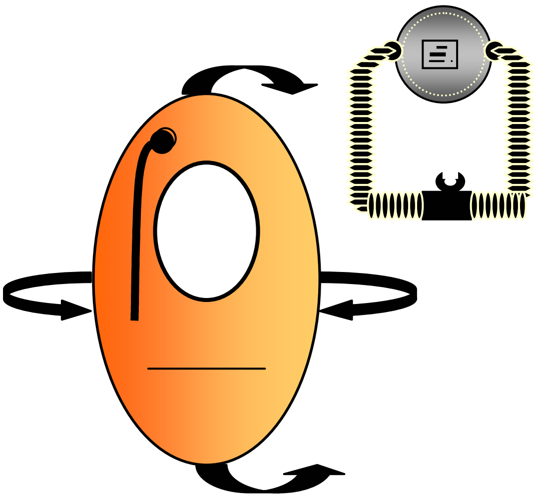
Inflator/regulators are popular in some areas. In an out of air situation, the diver will give the primary second stage to the diver who is out of air and will breathe himself from the inflator/regulator. There are rather a few pieces in a single housing, which makes them sensitive and less popular in areas where surf entries are made.

For the inflator mechanism, there are 3 basic types. All have a spring loaded button which opens a passage to allow the air from the intermediate pressure hose to flow into the BCD.



The mechanism to the left only has one o-ring. The piston is conical shaped at the end, sealing the passage of breathing gas. When the button is pushed, the seal will break and air will flow into the jacket. The spring will force the piston back in sealing position when the diver stops pushing the button. In the second model, the seal will break when pushing the button, because the conical shape of the housing will not allow the lower o-ring to seal when the button is depressed. The third model uses the upstream valve we know from the pilot second stages. As a matter of fact, it is the same valve as found in the inflator hose (and in bicycle tires).

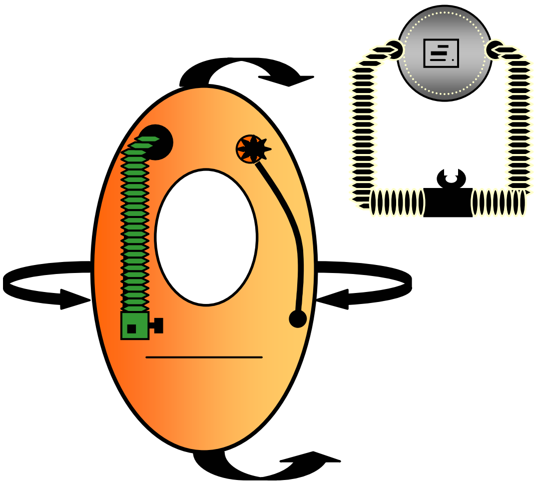
The History of BCD Bladders



In the early days of recreational diving (the time where the single hose regulator did not yet exist) divers used to go under water without a flotation device. This changed with the introduction of a safety vest. This is basically the same type of vest you find under your seat in a commercial airplane.

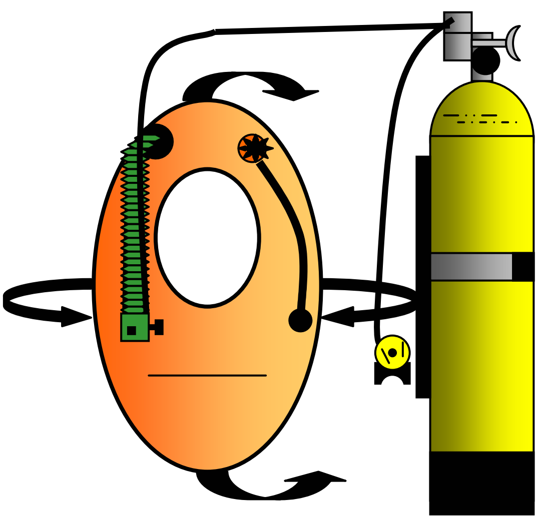
Initially, it was not the intent to use the vest under water. It was taken along to provide flotation at the surface in case of a problem. The vest had the typical small diameter hose we know from the safety vests in a plane and some were equipped with a CO_2 cartridge to allow automatic inflation.

With time, divers started to recognize the benefits under water. They inflated the vest to achieve neutral buoyancy at depth. As a consequence, the limitations of these vests became clear. Rather a few divers experienced an uncontrolled ascent, because the small diameter hose did not allow releasing air fast enough during the ascent and the absence of an overpressure relief valve cause some vests to rupture, instantly changing the uncontrolled ascent into an uncontrolled descend.



Due to these safety concerns and the widespread use of the vest to achieve neutral buoyancy under water, some new features were added to the vest. A hose with a large diameter allowed the diver to release the air faster and prevented an uncontrolled ascent. Even today you can still read in instruction books for diving that the hose of the BCD is to have a large diameter (although it is doubtful if there are still many around who know why it was written in the book).

The second feature was the overpressure relief valve and quick release, which was discussed on the previous page. In some cases the CO_2 cartridge was replaced with a small cylinder with high pressure air to allow the diver to inflate the vest automatically. These small cylinders were filled from the main cylinder before the dive, but were rather uncomfortable out of the water and it was hard to control the amount of air injected in the vest at once. Most divers preferred oral inflation during the dive, because it was easier to control.



After the introduction of the single hose regulator, it was only a matter of time until the inflator, which we still use today, was invented (1972). Rather than providing a separate air (or CO_2) source for the inflation of the vest, the inflator was connected with the first stage. The inflator was patented and initially the other manufacturers (who could not get around the patent) did their best to convince divers that the inflator was dangerous and not reliable, but did only slow the introduction down. You could not imagine today to dive without an inflator.