EASY THEORY BY MATT 062026

Hi! This document is a summary of the Dive Theory. It will help you study and review the topics you need to know for the IDC and prepare you for the PADI Instructor Exam.

Use this sheet and structure as a review of the Divemaster Theory before you start the IDC and as a quick reference to aid in your overall study program during the IDC.

Do not worry if there are some concepts that you don't fully understand, we will review it all during the IDC preparation and during the IDC program, but try to get as familiar as possible. The more effort you put in understanding this sheet now the easier the IDC will be. Enjoy and have fun!

If you are a Divemaster Candidate, this file covers many of the topics you are learning in your course. If you are considering taking the IDC in the future, this is a good tool to use in order to start preparing for it!

In addition to this document, you can use the App DiveEduApp, which provides exercises along with detailed explanations on how to solve them.
-> https://dive-education.com/en/the-dive-education-app/

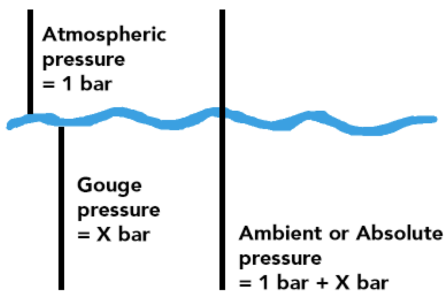
For any questions, contact me at matt@dive-education.com.

PADI CD Matt

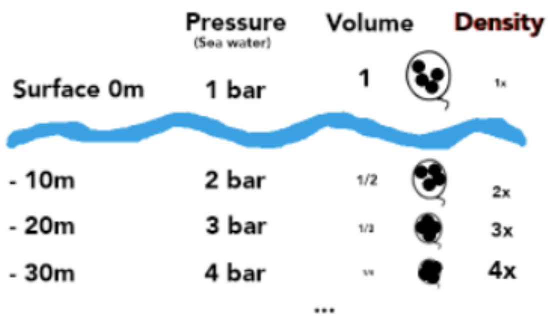
1 Physics

- The effect that light has when it hits the water is called refraction -> things look 33% larger, and 25% closer.
- Light is "absorbed" by water when it passes through water. This effect is called Light absorption and it makes colours duller (or even disappear) while going deeper. Red disappears first.
- If water is turbid (has particles) you may experience an effect called visual reversal -> an object looks farther away than it actually is. This is due to water turbidity.
- Water is much denser than air. For this reason:
  - Sound travel 4 times faster -> It seems the sound comes from overhead.
  - Heat is transported 20 times faster -> In water we lose heat 20 times faster than when dry.
- Heat loss underwater ->
  - Conduction (heat removal via direct contact)
  - Convection (heat removal via fluid movement)
  - Radiation (via electromagnetic waves, for example the sun)
  - Divers are mostly affected by Conduction –> water is a very good conductor
- There are different definitions for different pressures:
  - The pressure of the air on the surface (1 bar) is called Atmospheric Pressure
  - The pressure caused by the weight of the water is called Gauge Pressure:
    - In salt water every 10m = 1 bar
    - In fresh water every 10.3m = 1 bar

  - The Ambient pressure (also called absolute pressure) is the sum of the Gauge Pressure + Atmospheric Pressure (1 bar). This is the actual pressure of where a person is. To calculate it:
    - In salt water:
      - Depth (in meters) / 10 = Gauge pressure + 1 bar = Ambient pressure
    - In fresh water:
      - Depth (in meters) / 10.3 = Gauge pressure + 1 bar = Ambient pressure



- *Boyle's* law expresses the relationship between pressure, volume, and density. Remember the table:
    - Depth: 0m = Pressure 1 bar = Volume 1 = Density 1
    - Depth: 10m = Pressure 2 bar = Volume 1/2 = Density x2



- You will be asked to make some calculations.
  - Remember that a solid container never changes its size/volume
  - For calculations, always use ambient/absolute pressure
  - Going deeper, the volume becomes smaller – the density increases
  - Going shallower the volume becomes bigger – the density decreases
  - The deeper a diver is, the denser the air is, the more air is consumed
  - When calculating the difference in volume of a flexible container, always calculate the volume at the surface first, and then at the new depth. (Virtually bring the container to the surface and then to the new depth)

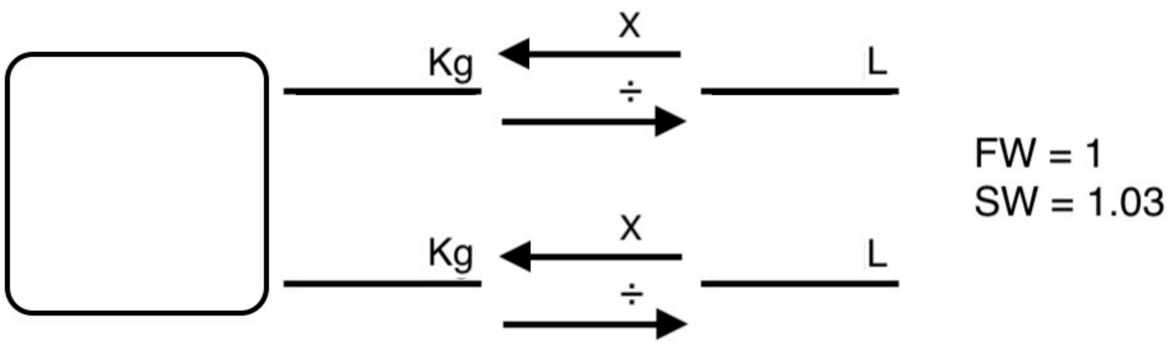
- ***Dalton's*** law says that the total of the partial pressures of the gases in a mix of gases is equal to the ambient pressure (for ex: Air at surface (21% O2, / 79% N): -> 0.21bar P.P.O2 / 0.79bar P.P.N)
  - The % of the gases inside a tank does not change with depth, the effect does, for example:
    - If you breathe from a tank with 32% O2 and 68% N at the surface. Your body will be affected with a partial pressure of 0.32 bar (32% of 1 bar) of oxygen and 0.68 bar (68% of 1 bar) of Nitrogen. The total of the two partial pressures will be the ambient pressure (0.32bar (O2) + 0.68bar (N) = 1 bar surface).
    - If you breathe from the same tank at 10m deep (where there are 2 bar of pressure) your body will be affected with a partial pressure of 0.64 (32% of 2 bars) bar of oxygen and 1.36 (68% of 2 bar) of Nitrogen. The total of the two partial pressures will be the ambient pressure (0.64bar (O2) +1.36bar (N) = 2 bar, at -10m).

- The 2 types of **oxygen toxicity**:
  - 1) When you breathe O2 at a pressure of 1.4 bars: When you are diving you always want to make sure that, depending on the % you have in the mixture and the depth, you never pass 1.4 bar of O2 partial pressure. That could cause a malfunction of the Central Nervous System (CNS) and lead to convulsions, which, underwater, can lead to drowning.
  - 2) When it has been breathed for too long: High level of oxygen can cause what is called Pulmonary Toxicity; a sort of burn of your lungs.

- ***Charles***'s law says that for each degree (Celsius) difference there is a pressure change of 0.6 bar. So if a tank is filled to 200 bar at 35°C and you put the tank in a 20 °C environment -> the difference of temperature (35 - 20 = 15°C) multiplied by 0.6 (15 * 0.6 = 9), will result in a pressure in the tank of 191 bar (200 bar – 9 bar).

- ***Archimedes***' principle says that an object immersed in water has an energy downward equal to its weight (in Kg) and an energy upward equal to the amount of water displaced (in Litres, L). The difference between those two energies make an object negative (sink), neutral (not sink/not float) or positively buoyant (float). You will be asked to solve some problems. **Remember**:
  - 1L of fresh water weights 1 Kg and displaces 1L
  - 1L salt water weights 1.03 Kg and displace 1L
  - You cannot add and subtract Kg with Litres so you always have to convert:
    - To convert Litres to Kilograms you have to multiply (X) for 1 or 1.03
    - To convert from Kilograms to Litres you have to divide (/) for 1 or 1.03

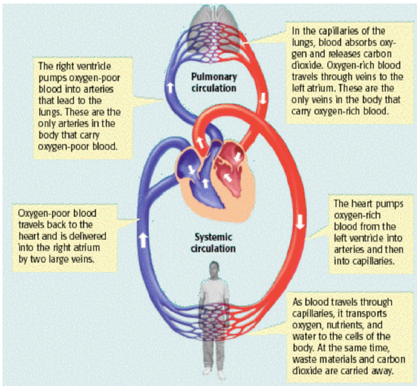
- You will be asked to calculate when an object becomes neutral, or how many litres do you need to add to a lifting bag in order to lift the object, or how negative an object is. You always have to read the question carefully and calculate accordingly.
- Use this template and then enter the data provided by the question:



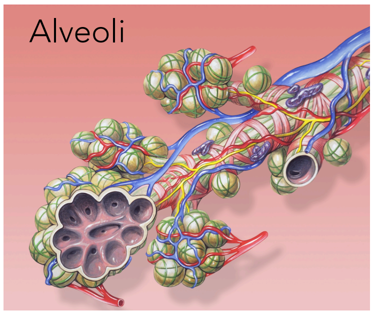
- Remember:
  - The depth does not affect the calculations
  - If an object is neutral in salt water and then put in fresh water, it will sink
  - If an object is neutral in fresh water and then put in salt water it will float
  - If an object is negative or positive in fresh or salt water and then respectively moved in the "other type" of water, you cannot define its buoyancy. (Because you do not know how buoyant the object is in the "first type of water")

- Absorption of gases, ***Henry's*** Law:
  - Gas dissolves in liquids. If you have a glass of water at sea level the pressure of the gas in the water is 1 bar. If you take the same glass of water and you put in a chamber with 2 bar of pressure, the gas in contact with the liquid will dissolve in the liquid. It will take some time and eventually the pressure of the gas in the liquid will reach 2 bar. This is called saturation.
  - If then you take the glass back to an ambient pressure of 1 bar the gas in the liquid will "exit" and the gas pressure in the liquid will decrease until it reaches 1 bar. If the pressure changes too quick, the gas that is "exiting" the liquid may form some bubbles, which would be defined as decompression sickness.
  - Our body is made of liquid (about 75% of water), so when our body is under pressure (under water) the gases we breathe are absorbed in our body. O2 is metabolized, but N stays in our body. The deeper we dive and the longer we stay underwater, the more N we have dissolved in our tissues.

2 Physiology



- **The respiratory system** allows the human body to inhale fresh air (about 21% of Oxygen (O_2) and 79% Nitrogen (N)) and exhale "used" air (about 16-17% of O_2, 3-4% of Carbon Dioxide (CO_2) and 79% of N). The fresh air travels through the trachea, bronchi and reaches the alveoli where gases exchange (fresh O2 diffuses into the blood stream, CO_2 is released back into the air through expiration) passing through small blood vessels called capillaries.



- **The circulatory system** delivers blood rich in O2 (blood in the arteries is bright red) to the tissues of the body. Once the tissues use the O2 (metabolize) and give back CO_2 ("waste"), the blood rich in CO_2 (blood in the veins is dark red) travels back to the lungs. The "engine", or "pump", that circulates blood around the body is the heart.
- The body uses O_2, while N_2 does not react chemically and simply dissolves in body tissues. A gas that dissolves in the body without chemically interacting with it is defined as an inert gas, such as nitrogen, helium, or argon).

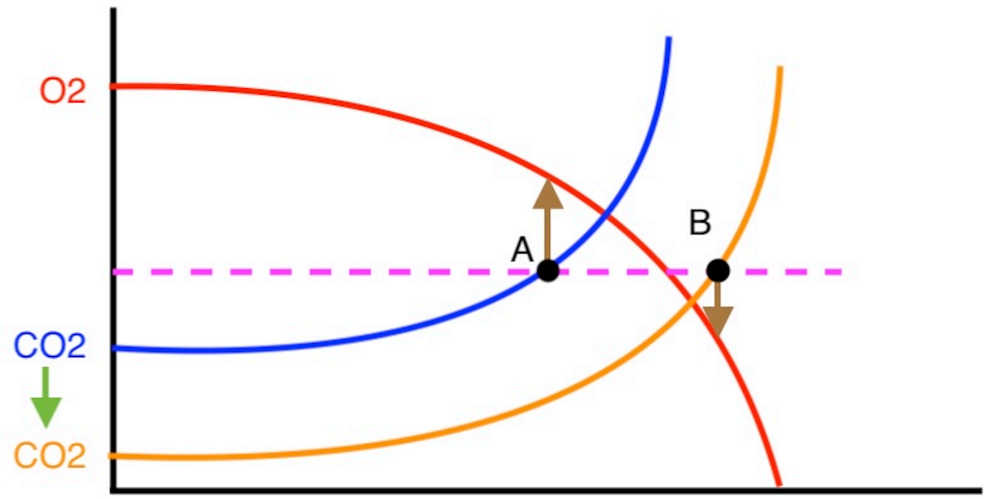
- Haemoglobin, (is a protein inside the red cells, which are inside the blood).
    - Haemoglobin binds chemically with oxygen and CO_2 to be transported in the body, (inert gases don't).
    - Haemoglobin binds 200 times more efficiently with Carbon Monoxide (CO) than with O2. For this reason, if you smoke you will have high levels of CO in your blood. When you go diving the pressure around you increases. If you smoke just before diving you will have a high level of Carbon Monoxide, and the increment of pressure causes you to have a high partial pressure. This is really dangerous and can lead to underwater unconsciousness.
- Gas absorption: As we saw with *Henry's Law* gas dissolves in liquids, and when we dive, Nitrogen dissolves in our bodies. When the level of Nitrogen reaches the maximum (the gas pressure equals the ambient pressure) saturation occurs.
- Let's say that a diver is diving and has a certain amount of N in his/her tissues. If the diver goes into shallower water (and so the ambient pressure drops), the pressure in the tissues is higher than the ambient pressure, (this situation is called super-saturation), if the diver ascends too quick, the gas dissolved in the tissue may not have enough time to "exit" and bubbles may form, this situation is called Decompression Sickness. The limit of Nitrogen or "maximum amount of super saturation that the body can tolerate" is called M value (this value depends on type of tissue, age, hydration, etc..).

- Decompression Sickness (DCS, also called Bends) is a situation where the body has Nitrogen bubbles in the body tissues. These bubbles, depending on where they are located, may cause different signs and symptoms.
  - Doctors define DCS with two definitions.
    - Type 1: Normally a situation of muscle pain only that occurs in limbs (often elbows, shoulders, knees), or cutaneous red rashes (usually on the upper chest), sometimes accompanied by general fatigue, malaise, mild dizziness.
    - Type 2: A life-threatening situation where the diver has symptoms that involves the brain, lungs or nervous system (numbness, tingling, paralysis, confusion) accompanied by unconsciousness, extreme fatigue.
  - The first aid is to give 100% oxygen to the diver and call EMS:
    - Doing this prevents more N entering the body and this helps drop N levels in the body. The divers still need to go to a recompression chamber in order to recompress N bubbles (!)
    - If 100% O2 is not available give any nitrox (if available), any percentage higher than 21% is better than air.
  - We are not doctors, but as diving instructors, you should be able to recognize these signs and symptoms. It is also very important not to "feed" symptoms to someone that may have DCS. For example; Ask "how do you feel?" not "Do you feel pain in your arm?"
  - On top of depth and length of the dive there are other factors that may increase the possibility to have DCS:
    - Levels of fat, age, dehydration, injuries, illness, alcohol, cold water, altitude.
  - After every dive, every diver has some small bubbles in their blood tissue. This is normal and it also happens when diving within limits, those bubbles are called silent bubbles and can be detected with a tool, a sonar called a "Doppler".

- Lung overexpansion: It is caused by the air expanding in the lungs and it can be classified within 4 different situations (**from the least to the most dangerous**):
  - 1. **Subcutaneous emphysema**: Gas that escapes from the lungs and accumulates at the base of the neck. It can cause voice changes and it is normally visible with bubbles under the skin;
  - 2. **Mediastina emphysema**: Gas that escapes from the lungs and accumulates in the centre of the chest;
  - 3. **Pneumothorax**: A collapsed lung. The gas is trapped between the collapsed lung and the pleura (inside skin that separates the lungs to the chest). Make the patient lay on their side with the collapsed lung down, so the "good one" can work properly;
  - 4. **Gas Air Embolism**: This is the most serious one. In this case a bubble of air has entered the blood stream due to a rupture in the alveoli (where the gases exchange in the lungs). The bubble can reach the brain; it is very serious and can have effect on the Central Nervous System (CNS). Signs and symptoms are similar to a stroke.

- Some definitions:
  - Decompression Illness (DCI) is a term that define both includes Decompression Sickness (DSC) and Lung Overexpansion (LO).
  - This is because the treatment for DCS and LO is the same: Provide pure oxygen if available, if not then the highest percentage of O2 available, call EMS, rest, provide medical attention, and send to a recompression chamber.
  - Symptoms of lung overexpansion normally appear immediately after the dive (pain in the lungs, chest). Symptoms of DCS can occur hours after the diver surfaces.
- Gas narcosis (formerly called nitrogen narcosis):
  - A situation that makes the diver feels "good", and relaxed. Sometimes too good that can make the diver act foolish and without a sense of danger. N and O2 have the same narcosis effect. It normally occurs at a depth deeper than 30m. In case you experience it, go up to a shallower depth and the narcosis should go away.
- The Mammalian reflex is a reflex that happens in our body due to the fact that during the evolution the human body, humans developed the ability to increase the time that they can hold their breath underwater. It is the same reflex that allows turtles to hold their breath for a long time.
  - It is triggered by having the face in the water
  - It slows down the heartbeat (= bradycardia) causing the body to use less oxygen.
- Some other definitions:
  - Baro = related to pressure
  - Trauma = injury
  - Brady = slow
  - Cardio = related to heart
  - Hypo = less (remember the hippopotamus lives underwater)
  - Hyper = more (remember a Hyperactive kid is always running around)
  - Thermo = related to temperature
  - Capnea = CO_2
  - Oxia = O_2
  - Hypercapnia = high level of carbon dioxide (CO_2). It is caused by breathing hard underwater (or not deeply, not releasing all the CO_2), for example while swimming against strong current. It can result in headaches, disorientation, and nausea. To avoid it breathe slowly and deeply.
  - Hypocapnia = low levels of CO_2, for example by hyperventilating. It can lead to interruption or malfunction of our normal breathing cycles because carbon dioxide stimulates breathing.
  - Hypoxia = low levels of O2. It can describe the status of shock or shallow water blackout. While freediving, the body "burns" the O2. If you are at depth the pressure of the water maintains an adequate level of Oxygen Partial Pressure. When you shallow up the pressure drops and that can cause shallow water blackout
  - Hyperoxia = high levels of O2. Can cause, for example, Oxygen toxicity.

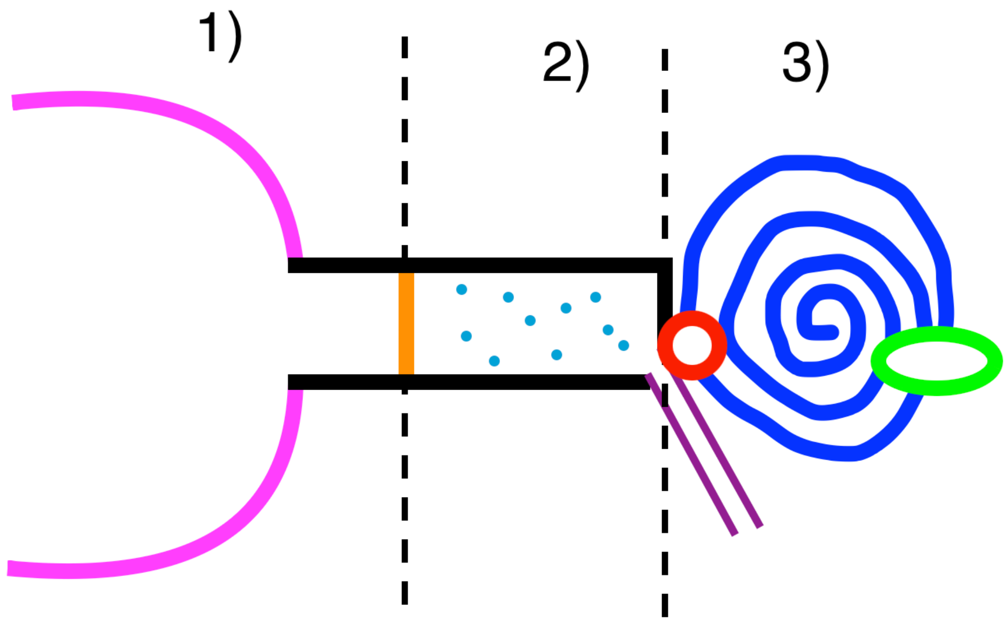
- While **freediving** you hold your breath. During this time, the level of O_2 decreases and the level of CO_2 increases. At some point, the body starts feeling the need to breathe, this is called urge to breathe, and it is triggered by a certain level of CO_2 (point A), not by a low level of O_2. When this happens (without hyperventilating), the level of O_2 is still relatively high (point A).
  In the past, it was common practice to hyperventilate before freediving in order to lower the level of CO_2 in the body. This is very dangerous because hyperventilation only reduces CO_2 levels and does not increase O_2 levels.



  In this situation the urge to breathe is triggered later (point B), where the level of O_2 is much lower (point B).

  While at depth, the ambient pressure is high; therefore, the partial pressure of oxygen (even if the level of O_2 is low) is still high enough to keep the freediver conscious. As soon as the freediver ascends, the ambient pressure drops, and therefore the partial pressure of O_2 also drops, risking what is called **shallow water blackout**.
- In the body we have some air spaces through which air "travels" to go in and out of our body, for example in the trachea. Those are called "dead air spaces". If you breathe short and rapid breaths you keep breathing the same air, meaning that you keep rebreathing the CO_2 you just expelled (causing Hypercapnia). This is the reason why it's important to always breathe deeply.
- Squeeze: If a diver does not equalize the body air spaces, the "feeling" caused by the pressure difference is defined as a "squeeze". That can happen for example when the diver is descending and does not equalize the ears. A squeeze can also be caused by air trapped in a place where it cannot escape; for example when a diver dives with a cold and manages to descend, but then the air is trapped while ascending due to the cold (reverse block). A "forced" squeeze can be very painful and can cause serious injuries (barotrauma).
- The carotid sinus reflex malfunction is a situation that occurs when the carotid artery (the "hose" in our neck, jugular, that transports arterial blood, reach in O2 to the brain) is under pressure. Due to the pressure the flow is not correct and the brain "feels" that it is not receiving enough O2 and will then change the heartbeat. This can be caused by the hood being too tight.

- As we know, water conducts heat much faster than air, for this reason, divers may feel cold underwater if not diving with proper suits. In extreme cold conditions, this can lead to hypothermia; a very serious condition caused by an extended period of exposure to cold environments. It can lead to loss of concentration, poor judgment, loss of control, and death, if not properly treated.
- In the same way, a diver, due to the fact that he is often exposed under the sun, can suffer if the body has been exposed to a hot environment for too long. There are two different definitions you should know:
  - Heat exhaustion: The diver has a weak rapid breath and pulse, is sweating, has nausea, and feels fatigue. Give the diver water and keep him/her out of the sun.
  - Heatstroke: The diver has a strong rapid pulse, is not sweating, and is confused. This is a very serious situation; the body cannot react and cannot even sweat. Try to cool down with a fresh towel and look for medical care.
- The ear: is very affected while diving. There are 3 main parts that compose the ear:
  - 1) The outer ear: This is the visible part (it has no airspaces and doesn't need to be "equalized"), including the ear lobes and **ear canal**. The eardrum separates the outer ear from the middle ear. Sound travels through the ear canal to the eardrum which separates the outer ear and the middle ear.
  - 2) The middle ear: This is the most affected of the 3 parts by pressure changes (because it has air in it). This is the area affected by equalizing vie the eustachian tube. If a diver equalizes forcefully, it may cause a rupture in the round window.
  - 3) The inner ear: Is very delicate but well protected. Contains the cochlea (used for hearing) and the vestibular organs (used for balance) and the oval window.

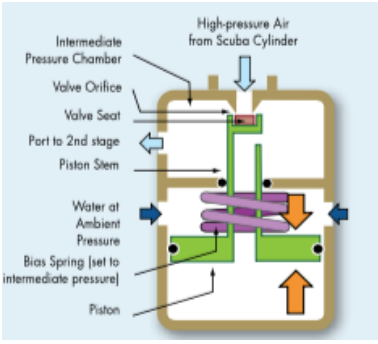
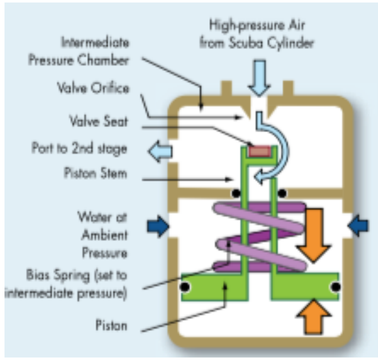
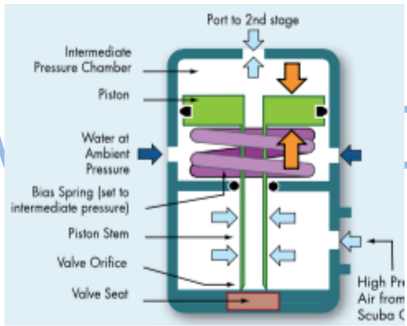
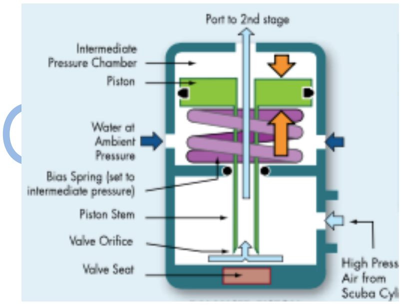


3 Equipment

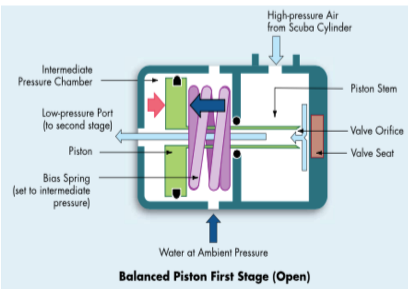
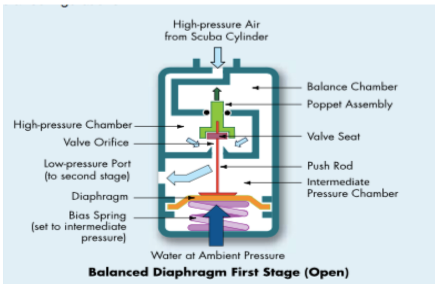
- SCUBA stands for "Self Contained Underwater Breathing Apparatus"
- **Tanks** are the "bottle" in which we put compressed air (or different gases), they can be made of Aluminium or Steel.
  - Each tank has the followings marks:
    - DOT (Department of Transportation standards) or DOT/CTC: Those are marks that says that the tank it has been approved from the government
    - The metal type: 3A or 3AA = Steel / 3AL = Aluminium
    - The working pressure: this is the maximum pressure a cylinder should be filled with. Normally it is written in psi (for example 3000psi = 205 bar)
    - The serial number: This is a unique number that identifies the tank.
    - Hydrostatic test date + Mark: this is the date of the last Hydrostatic test + the symbol of the tester (registered with the government). For example 04*17 (last hydrostatic test was on April 17 by the tester with the registered symbol "*")
    - Main differences:
      - Aluminium = flat bottom / Steel = round bottom.
      - Both max pressure 220 bar
      - Aluminium = easy to clean aluminium oxide / Steel = rust, difficult
      - Aluminium = changes buoyancy, negative when full, becomes positive when at 80 bars / Steel = always negative
    - The visual inspection should happen once a year. The tank is emptied, opened, checked for visible damages (inside and outside), checked for galvanic reaction (reaction in the neck due to the different metals of the tank and the valve), cleaned, and the O-ring checked/changed and greased.
    - During the hydrostatic test, a tank is filled with water and put in a container (also filled up to the top with water). Then the tank is closed and some pressure is put inside it (5/3 the working pressure). The tank has small dilatation causing the water from the container to fall outside the borders. Then the pressure is released, the tank returns (with some acceptable differences) to its original size. At this point the level of water is measured to see how much the tank has "dilated". If it is inside the standards the tank passes the hydrostatic test, if not a hole is drilled in the tank making it unusable. The rule about how often the test must be done differs from country to country. Normally the first time is after 5 years and then every 2 to 4 years. A tank should go through a Hydrostatic test after being sandblasted, after an impact or exposure to heat.
- Tanks **valves** are used to open and close the tank. There are two types:
  - K-valve: is a simple open-close valve (ON-OFF);
  - J-Valve: is a reserve system that is activated when you reach 30-50 bars of pressure in your tank. In the same way a reserve switcher in a motorbike gives you access to the reserve fuel from a tank, the J-Valve gives you access to the reserve part of air. It does not give you more air!

- The first stages of the regulator connect to the tank valve, there are two different types:
  - DIN-Valve (stands for *Deutsche Industrie Norm – German Industrial Standards*); the first stage is screwed directly in the tank valve. The first stage has its own O-ring.
  - Yoke-Valve (or international): uses the O-ring that is in the tank valve to seal the circuit. This is the most commonly used first stage valve.
- A burst disc is a security feature found in the tank Valve. It ensures that the tank will not reach a dangerous pressure, possibly causing an explosion. It is composed of a disk that would break if the tank pressure rises above about 140% of the working pressure (i.e. if the tank has been left out in the sun).
- While diving, you can dive with different types of breathing systems:
  - The open circuit: It is the most common, the diver breathes in the gas from the regulator and releases bubbles in the water while exhaling;
  - The Semi-Closed Circuit: Made of a circuit where the diver keeps breathing the same gas. The circuit is filtered to extract CO_2 and a tank with enriched air continuously inserts a mix of Enriched air into the circuit. A small amount of gas is released (bubbles) from the system continuously (due to the gas that "goes in the system").
  - The closed circuit: (CCR – Close Circuit Rebreather): Very similar to the semi closed circuit, a CCR has a circuit from where the diver keeps breathing the same gas. The circuit is completely closed; no gas is released in the water. The gas is filtered to extract the Co2 and 2 tanks with O_2 and a diluent (normally air, nitrox, or helium) refill the circuit from the Co2 that has been taken away. Everything is controlled by CPU and sensors.
- Most people use open water circuit while diving, so here is how a regulator works:
  - The pressure from the tank (50 to 200 bars) goes in to the first stage. When the diver inhales, he creates a difference of pressure in the second stage, that opens the circuit. The air pressure in the first stage is dropped to about 10 bar + ambient pressure. This pressure, which exits from the first stage, is called intermediate pressure.
  - The air passes through the hose and reaches the second stage. The second stage drop the pressure from the intermediate pressure (10 bars + ambient pressure), to ambient pressure, allowing the diver to breathe the gas at ambient pressure.
- The first stage: can be balanced or unbalanced, see how it works:
  - Balanced first stage: Inside the first stage, the high-pressured gas from the cylinder reaches a chamber and stays around both sides of the valve that open and close in order to deliver air. The gas does not directly press on the valve, so the pressure does not assist in opening it.
    - The pressure from the tank neither helps nor encumbers the opening of the valve.
    - The depth does not affect the eases of breathing.
    - The amount of people breathing from at the same time, or the number of devices connected and used at the same time does not effect the ease of breathing.

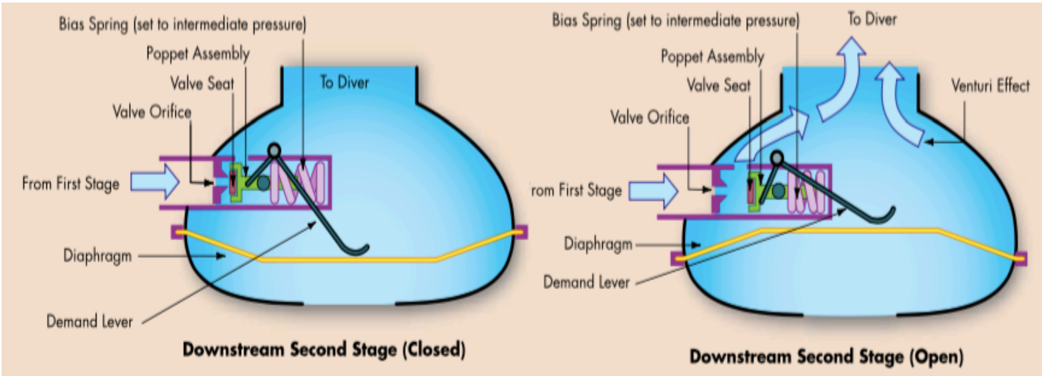
- <u>Unbalanced first stage</u>: The gas from the cylinder presses directly on the valve and <u>assists in opening it</u>.
    - The pressure of the tank <u>influences the ease</u> of opening the valve. The higher the pressure, the easier it is to breathe.
    - The depth <u>affects the ease of breathing</u> -- the deeper you go, the more difficult it is to breath
    - The more people you have breathing or devices used simultaneously, the more <u>difficult is to breathe.</u>

	Closed	Open
Unbalanced	When you're not inhaling, the gas inside the intermediate pressure chamber applies a force to the piston that is equal to the force of the bias spring plus the ambient pressure. The piston does not move and the valve stays closed. 	When you inhale, gas pressure in the intermediate pressure chamber drops, the valve opens, and gas flows. When the cylinder is full, the opening force against the valve seat is the greatest and it takes the least effort to open it. As the cylinder pressure drops, it becomes harder to breathe because there's less force on the valve. 
Balanced	When you're not inhaling, the gas inside the intermediate pressure chamber applies a force to the piston that equals the force of the bias spring plus the ambient pressure. The piston doesn't move and the valve stays closed. 	When you inhale, gas pressure in the intermediate pressure chamber drops, the valve opens, and the air flows. Because gas from the cylinder never exerts pressure on the piston stem base, it has little effect on breathing resistance. Therefore, breathing effort remains virtually unchanged until the cylinder is nearly empty. 

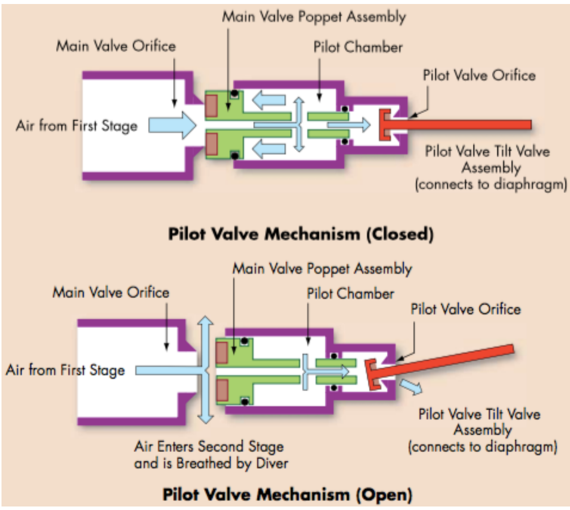
- The first stage can also have two different "ways" to work, defined as <u>Piston first stage and Diaphragm first stage</u>:

	Piston: The water "goes" inside the 1st stage	Diaphragm: The water does not go inside the 1st stage
	 Balanced Piston First Stage (Open) Fewer moving parts -> <u>easier to service</u>	 Balanced Diaphragm First Stage (Open) Diaphragm separates the interior parts from the water -> reduces corrosion and contamination (<u>environmentally sealed</u>)

- The second stage can be classified in 2 different types; a downstream valve second stage, and a Pilot valve second stage. Nowadays almost every used second stage is downstream. Let's see how they work:
    - Downstream valve: Also defined as "**on demand valve**". When the diver is not inhaling, the valve is closed and no air flows into the second stage. When the diver inhales, he creates a situation with less pressure in the chamber, this moves the diaphragm, which moves the demand lever, which opens the valve. The diver can achieve the same result when he pushes on the purge button in the front part of the second stage (he pushes the diaphragm). These types of valves are mechanically simple, so reliable. If a downstream valve fails, it always fails in the open position, resulting in a free-flow situation. For this reason, this is called a **fail-safe design**:



- Pilot valve: When the diver inhales, the diaphragm depresses a lever on a small valve. The small valve releases air pressure that in turn opens the larger main valve:

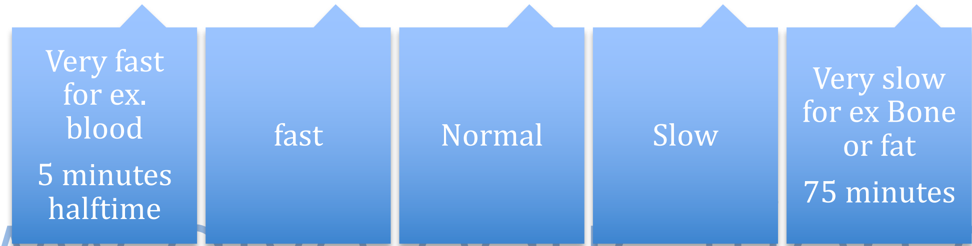


- SPG: In order to know how much air a diver has in the tank, we use a **Submersible Pressure Gauge** (SPG). An SPG is a gauge that has a Burdon tube inside. The Burdon tube is (usually) a copper tube (or spiral) that tends to straighten if the pressure inside the tube increases. A mechanical system (a needle and a scaled display), then allows the diver to read how much air is there in the tank. The Burdon tube can be open or oil-filled; the oil-filled ones have the mechanical part sealed and protected from the water.

- Depth Gauges: Nowadays, almost every diver uses a computer as a depth-measuring device. However, some of the "old-school" devices are still around, especially because they are low-cost. Let's see what they are and what the differences are between them:
  - Capillary: Consists of a small air-filled tube, sealed on one side. While diving, the air gets compressed and the diver can read from the scale how deep he is. It is simple and accurate at shallow depth. It is difficult to read when the diver goes deeper. This Gauge is particularly good for altitude dives because you can adjust the "starting" pressure accordingly with the altitude.
  - Diaphragm gauges: A flexible diaphragm connects to the gauge needle through a series of connecting rods, levers or gears.
- If not specified differently from the manufacturer, when diving with nitrox, the equipment (regulators) are set for a maximum of **40% O_2** in the gas mixture.

4 Decompression Theory - RDP

- *John Scott Haldane* developed the first mathematical decompression model and, in 1906, created the first diving tables based on it. He was the first that theorized the absorption of Nitrogen while diving:
  - When a diver is breathing at depth, the nitrogen pressure of the gas that he is breathing is higher than the nitrogen pressure in his body. So, due to Henry's Law, more nitrogen dissolves into the body tissues.
  - After a certain amount of time, the nitrogen pressure equalizes and the body cannot absorb any more nitrogen. This is called saturation.
  - While ascending, the nitrogen pressure in the body is higher than the nitrogen in the breathing gas. That causes tissues to release nitrogen.
  - If the ascent rate is too fast, bubbles may form and cause decompression sickness.
- Haldane discovered that the body absorbs and releases nitrogen at different speeds depending on which part of the body. He theorized different tissue groups (called compartments) in order to simulate body tissues absorbing and releasing nitrogen.
- Haldane's first model had 5 theoretical compartments.



- Each compartment has a halftime for the rate at which it absorbs and releases nitrogen. For example, at a certain depth, a 5-minute half time compartment will:
  - 1st After 5 minutes, it reaches 50% of his saturation;
  - 2nd After another 5 mins (10 total), it reaches 75% (50% + 50% of the rest).
  - 3rd After another 5 mins (15 total), it reaches 87.5% (75% + 50% of the rest).
  - 4th After another 5 mins (20 total), it reaches 93.75% (87.5% + 50% of the rest).
  - 5th After another 5 mins (25 total), it reaches 96.875% (93.75% + 50% of the rest).
  - 6th After another 5 mins (30 total), it reaches -> 100% (After 6 half times, the compartment is considered full.)
    - If you are asked to calculate the pressure in a 5-minute halftime tissue after 10 minutes dive at 18m:
      - 1) 10 minutes = 2 halftimes -> 75%
      - 2) 75% of 18m = 13.5
      - 3) The pressure in that tissue is 13.5 msw (metres of sea water)
- While diving and going at different depths, each compartment will have different levels of Nitrogen. Some will therefore be "taking N in" while some will be "releasing N".
  - Each compartment has a limit (pressure, amount of Nitrogen) that it can have when surfacing. This limit is called the **M-Value**.
  - The compartment that has the level of nitrogen closest to its M-Value is the compartment that is setting the limits to the no decompression (it is called controlling compartment). When any compartment reaches its M-value, it means

that the diver is at the no-deco limit. The diver must ascend or the dive will become a decompression dive. During each dive, a diver "decompresses" because the body releases nitrogen. However, in a so-called decompression ("deco") dive, the diver must perform decompression stops because the level of nitrogen has exceeded the M-value. This should not happen in a recreational dive, since the main point of recreational diving is to always have the possibility of ascending directly to the surface without mandatory decompression stops.

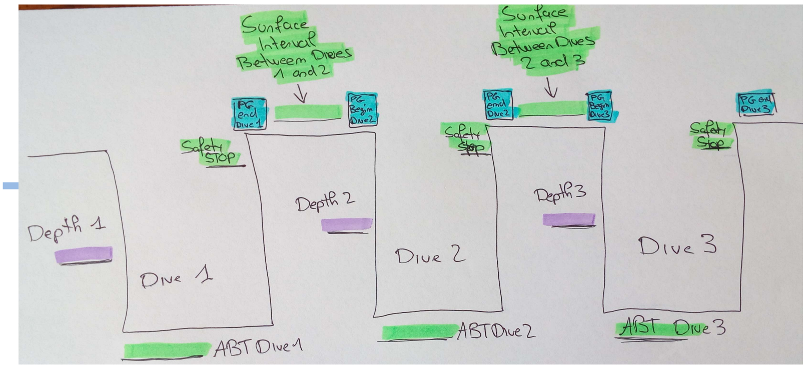
  - In order to be reasonably safe, a diver will always dive <u>without exceeding the M-Value.</u>
  - The slower the compartment, the lower the M-value. The faster the compartment, the higher the M-value.
  - M-Values are the results of many years of tests.
  - M-Values are calculated for <u>surfacing at sea level</u>. This is the reason why you need to apply special procedures when diving at altitudes above 300m.
- The first tables used for diving were the **<u>US Navy</u>** tables, originally designed in the 1950's for military use. The tables have these characteristics:
  - <u>6 compartments</u> with a slowest halftime of <u>120 minutes.</u>
  - The compartments were releasing nitrogen on the surface at the same speed as they were getting nitrogen while diving. (Each compartment with different halftime).
  - So they created the table based on the <u>120 minutes half time</u> to calculate the surface interval. Doing this, the table take in consideration the slowest, the last compartment to become "empty". When the slowest compartment is empty, then the other, faster compartments also are. This is the reason why it takes 12 hours (720 minutes = 6 x 120 minutes) to be "clean" when using their tables.
  - These tables were tested with US Navy divers, all male in their 20's and 30's and reasonably fit.
- In the **<u>1980's Dr *Raymond Rogers*</u>** hypothesized that the USN Navy tables were not good for recreational dives. Extra-long surface intervals were not optimized for repetitive dives and the test group used to compile the tables didn't reflect recreational divers (who include females and people of all ages).
- He started do hyperbaric tests. In 1988, in collaboration with DSAT (Diving Science & Technology), he published the new **<u>RDP</u>** tables using <u>14 compartments and 60 minutes</u> as slowest compartment (more suitable to recreational divers).
- Differences between US NAVI and PADI RDP:

US NAVY	RDP
For decompression	Not for decompression
<u>6 compartments / 120 minutes halftime</u> (Slower gas washout) Theoretically clear after 12h	<u>14 compartments / 60 minutes halftime</u> (Faster gas washout) Theoretically clear after 6h
For longer surface interval, no repetitive dives. Shorter bottom time on repetitive dives. (For military use.)	For multiple dives with short surface intervals. Longer bottom time on repetitive dives. (For average recreational dives.)

- General procedures for using the RDP (read this carefully!):
  - The Letter in the tables (pressure groups) cannot be interchanged with other type of tables (i.e. with the US Navy tables). However you can interchange with other PADI tables (like nitrox tables).
  - When you are planning a dive in cold water, plan it 4m deeper than what your actual dive depth is going to be.
  - Always plan deeper dives before shallower dives.
  - Maximum depths:
    - Discover Scuba Diver/Scuba Divers: 12m
    - Open Water Divers: 18m
    - Divers with greater training and experience: 30m
    - 40m is the maximum training depth for Deep Specialty Course and the Recreational Dive Planner. 42m is for emergency purposes only.
  - When planning a dive shallower than 10 metres, plan it as if it will be at 10 meters.
  - When planning, always use the exact or next greater depth and time (in order to be conservative).
  - Ascend at a maximum speed of 18 metres per minute.
  - When planning 3 or more dives and end one of those dive in pressure group:
    - W or X: the minimum surface interval between all next dives is 1 hour
    - Y or Z: the minimum surface interval between all next dives is 3 hours
  - A 3-minute safety stop at 5m is compulsory when:
    - Diving deeper than 30m.
    - When you dive within 3 pressure groups of your NDL (grey boxes)
    - When you dive to the NDL of the RDP (black box)
    - It is recommended to do a safety stop after each dive.
  - Never attempt to recompress a diver that has DCI symptoms.
  - Emergency decompression:
    - An emergency decompression stop for 8 minutes at 5m must be made if a no-decompression limit is accidentally exceeded by 5 minutes or less. (Upon surfacing, the diver must stay out of the water at least 6 hours before making another dive).
    - If a no-decompression limit is exceeded by more than 5 minutes, a decompression stop at 5m for not less than 15 minutes (or until air in the tank is finished) is required. (Upon surfacing, the diver must remain out of the water at least 24 hours prior to making another dive.
  - Using the RDP at altitudes 300m above sea level requires the use of special training and procedures.
  - Wait before fly a minimum of 12 h after 1 dive, 18 h after repetitive dives.
- Computers work the same way as table do, calculating the amount of N in the body depending in how deep and how long the diver has been diving. The big advantage is that they offer maximum bottom times by essentially writing a custom dive table while diving, eliminating unnecessary rounding. You should always read the manual first when you buy a new computer!

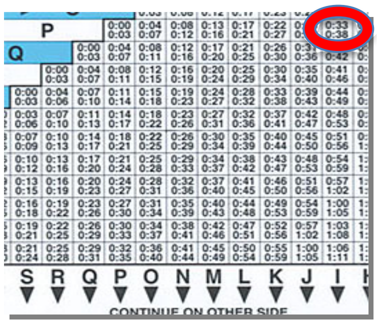
4.1 How to use the RDP tables

- The rules described previously are written in the bottom part of the back of the RDP.
- Definitions:
  - o <u>Actual Bottom Time (ABT)</u>: Time from the beginning (when the diver starts the descent) of the dive to the beginning of the final ascent to the safety stop
  - o Safety stop: A "3-minute at 5 meters" stop (Not counted in the bottom time)
  - o <u>Surface interval (SI)</u>: Time from the minute the diver surfaces to the minute he start the descent to the next dive.
  - o <u>Residual Nitrogen Time (RNT)</u>: Amount of Nitrogen (in minutes) from previous dives. This time must to be added to the ABT in order to find the:
    - ▪ <u>Total Bottom Time (TBT)</u> depth
  - o <u>Pressure Group (PG)</u>: The amount of Nitrogen expressed with a letter, (where A is very low and Z is very high) that a diver has after one or multiple dives.
  - o <u>No Decompression Limit (NDL)</u>: Limits in minutes where a diver can stay without reaching the decompression limit.
  - o <u>Total Bottom Time</u>: Is the sum between the ABT and the RNT. This is the time a diver needs to use in order to find his pressure group after a repetitive dive (you will see in the next session).
- Always draw a schema like this, in order to have all the data in the right place:
  - o Purple = Depth in metres
  - o Green = Time in minutes
  - o Blue = Pressure Group in Letter



- <u>How to calculate the PG</u> at the end of these 3 dives: (Dive 1: 21 metres for 31 minutes, SI of 34 minutes; Dive 2: 17 metres for 27 minutes, SI of 45 minutes; Dive 3: 14 metres for 45 minutes)
  - o 1) Write all the information you know in the schema and add every info you discover.
  - o 2) Go to the top of Table 1 and look for 22m (there is no 21, you have to use 22 to be conservative), follow the number down until you reach 31 minutes (there is no 31 so you have to use 32). Stay on that line, follow to the right and you will find the Pressure Group P.

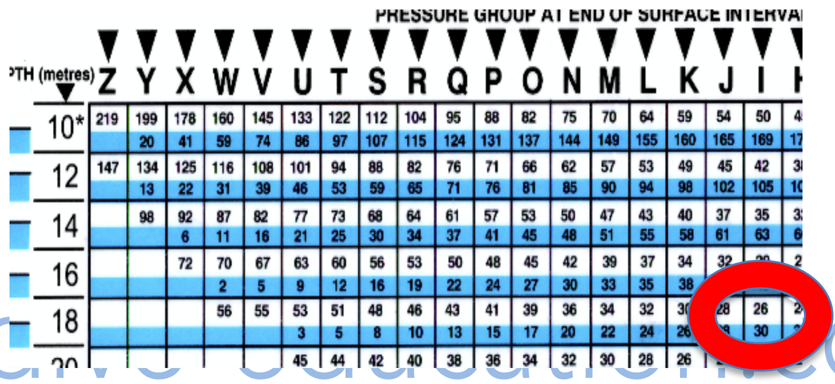
- 3) Continue to the right until you find the square that includes the SI you are doing between dive 1 and 2 (34 minutes). You will find that 34 minutes is between 0:33 and 0:38, follow <u>down</u> and you will find the PG I.



			P 0:00–0:03	0:04–0:07	0:08–0:12	0:13–0:16	0:17–0:21	0:22–0:27	[illegible]	0:33–0:38
		Q 0:00–0:03	0:04–0:07	0:08–0:11	0:12–0:16	0:17–0:20	0:21–0:25	0:26–0:30	0:3[illegible]–0:36	[illegible]–0:42
	0:00–0:03	0:04–0:07	0:08–0:11	0:12–0:15	0:16–0:19	0:20–0:24	0:25–0:29	0:30–0:34	0:35–0:40	0:41–0:46
0:00–0:03	0:04–0:06	0:07–0:10	0:11–0:14	0:15–0:18	0:19–0:23	0:24–0:27	0:28–0:32	0:33–0:38	0:39–0:43	0:44–0:49
0:03–0:06	0:07–0:10	0:11–0:13	0:14–0:17	0:18–0:22	0:23–0:26	0:27–0:31	0:32–0:36	0:37–0:41	0:42–0:47	0:48–0:53
0:07–0:09	0:10–0:13	0:14–0:17	0:18–0:21	0:22–0:25	0:26–0:29	0:30–0:34	0:35–0:39	0:40–0:44	0:45–0:50	0:51–0:56
0:10–0:12	0:13–0:16	0:17–0:20	0:21–0:24	0:25–0:28	0:29–0:33	0:34–0:37	0:38–0:42	0:43–0:47	0:48–0:53	0:54–0:59
0:13–0:15	0:16–0:19	0:20–0:23	0:24–0:27	0:28–0:31	0:32–0:36	0:37–0:40	0:41–0:45	0:46–0:50	0:51–0:56	0:57–1:02
0:16–0:18	0:19–0:22	0:23–0:26	0:27–0:30	0:31–0:34	0:35–0:39	0:40–0:43	0:44–0:48	0:49–0:53	0:54–0:59	1:00–1:05
0:19–0:21	0:22–0:25	0:26–0:29	0:30–0:33	0:34–0:37	0:38–0:41	0:42–0:46	0:47–0:51	0:52–0:56	0:57–1:02	1:03–1:08
0:21–0:24	0:25–0:28	0:29–0:31	0:32–0:35	0:36–0:40	0:41–0:44	0:45–0:49	0:50–0:54	0:55–0:59	1:00–1:05	1:06–1:11
S	R	Q	P	O	N	M	L	K	J	I

CONTINUE ON OTHER SIDE

- 4) You know that you are starting the 2nd dive with an amount of Nitrogen in your body equal to PG I. You also know that you want to go to 17m. (Guess what? There is no 17, so you have to use 18.) Take the table in the back and look for the information you find in the cross between the line 18m and the row I. You will find two numbers, 26 (on the top, white background) and 30 (on the bottom, blue background). 26 minutes is the RNT from the previous dive(s), 30 is the NDL for a dive at 18m starting with PG I.



PRESSURE GROUP AT END OF SURFACE INTERVAL

DEPTH (metres)	Z	Y	X	W	V	U	T	S	R	Q	P	O	N	M	L	K	J	I
10*	219	199 / 20	178 / 41	160 / 59	145 / 74	133 / 86	122 / 97	112 / 107	104 / 115	95 / 124	88 / 131	82 / 137	75 / 144	70 / 149	64 / 155	59 / 160	54 / 165	50 / 169
12	147	134 / 13	125 / 22	116 / 31	108 / 39	101 / 46	94 / 53	88 / 59	82 / 65	76 / 71	71 / 76	66 / 81	62 / 85	57 / 90	53 / 94	49 / 98	45 / 102	42 / 105
14		98	92 / 6	87 / 11	82 / 16	77 / 21	73 / 25	68 / 30	64 / 34	61 / 37	57 / 41	53 / 45	50 / 48	47 / 51	43 / 55	40 / 58	37 / 61	35 / 63
16			72	70 / 2	67 / 5	63 / 9	60 / 12	56 / 16	53 / 19	50 / 22	48 / 24	45 / 27	42 / 30	39 / 33	37 / 35	34 / 38	32 / [illegible]	[illegible]
18				56	55	53 / 3	51 / 5	48 / 8	46 / 10	43 / 13	41 / 15	39 / 17	36 / 20	34 / 22	32 / 24	30 / 26	28 / [illegible]	26 / 30
20						45	44	42	40	38	36	34	32	30	28	26	[illegible]	[illegible]

- 5) You planned your 2nd dive at 18 (yes, 17, but you use 18 for the calculations) metres for 27 minutes. Your ABT is going to be 27 minutes, but you want to add 26 minutes (your RNT from the previous dive(s)) to the calculations. You will find out that 27+26=53. Now you have to go back to Table 1 and look for the PG after a dive at 18m for 53 minutes, -> U!
- (In other words: "Diving at 17m for 27 minutes starting with a PG I is like diving a first dive (without any Nitrogen from previews dives) at 17 metres for 53 minutes".)
- 6) Try to find the PG at the end of the 3rd dive -- you should find PG V.

- If you have to find out the **<u>minimum SI between two dives</u>** (for example Dive 1: 30 metres, 20 minutes; Dive 2: 25 metres, 15 minutes):
  - 1) Calculate the PG at the end of the first dive -> 30m 20' -> N
  - 2) Find on the 3rd table the minimum PG needed in order to dive at 25m for 15'. The NDL is the number in the blue area, so follow the line of the depth (25m in this case) and go right until you find at least 15 minutes. Once you do that, look at the top in order to see the PG you need to be (in this case, F).
  - 3) Look on Table 2 and find out how many minutes are needed to go from N to F -> from 0:44 to 0:51 -- the answer is 44 minutes.

4.2 How to use the eRDPml

- The rules described previously are written on the inside cover of the eRDPml.
- In the same way we did for the tables, let's see how to calculate the PG at the end of these 3 dives: (Dive 1: 19 metres for 43 minutes, SI of 56 minutes; Dive 2: 17 metres for 32 minutes, SI of 1h and 10 minutes; Dive 3: 16 metres for 45 minutes)
  - 1) Write all the information you know in the schema and add every info you discover
  - 2) Select MODE -> Dive Planning -> ENTER -> Multilevel Dive? -> NO -> First Dive? -> YES -> Depth? -> 19 ENTER -> the eRDPml informs you that the NDL is 45 minutes -> ENTER -> ABT? - 43 ENTER -> the eRDPml informs you that you have to follow Rule 2 (3m safety stop) -> ENTER -> the eRDPml informs you that the Pressure Group after this dive is T -> ENTER
  - -> Surface Interval? 56 ENTER -> the eRDPml informs you that the PG after the SI is H -> ENTER -> Depth? 17 ENTER -> the eRDPml informs you that the ANDL is 32 minutes -> ENTER -> ABT? 32 ENTER -> the eRDPml informs you that you have to follow Rule 2 (3m safety stop) -> ENTER -> the eRDPml informs you that the Pressure Group after this dive is W -> ENTER
  - …What's the PG at the end of the third dive? W? Correct!
- If you have to find out the minimum SI between two dives (for example Dive 1: 20 metres 33 minutes; Dive 2: 20 metres 25 minutes):
  - 1) Calculate the PG at the end of the first dive -> 20m 33' -> O
  - 2) Select MODE -> Surface Interval-> ENTER -> First Dive? -> NO -> PG end dive1? -> O -> ENTER -> Depth? -> 20m -> the eRDPml informs you that the ANDL is 39 minutes -> ENTER -> ABT? -> 25m ENTER -> the eRDPml informs you that you have to follow Rule 2 (3m safety stop) -> ENTER -> min SI 42 min.

- You may be asked to calculate the PG on a Multilevel dive (for example Level 1: 29 metres for 8 minutes; Level 2: 19 metres 12 minutes; Level 3: 14 metres for 18 minutes):
  - 1) Write all the information you know in the schema and add every info you discover
  - 2) Select MODE -> Dive Planning -> ENTER -> Multilevel Dive? -> YES -> First Dive? -> YES -> Level 1? -> 29 ENTER -> the eRDPml informs you that the NDL is 20 minutes -> ENTER -> ABT? 8 -> ENTER -> the eRDPml informs you that the PG after the first level is C -> ENTER -> Level 2? -> 19 -> ENTER -> the eRDPml informs you that the Multilevel limit (ML) is 27 minutes -> ENTER -> ABT? 12 -> the eRDPml informs you that the PG after the second level is J -> ENTER -> Level 3? -> 14 ENTER -> the eRDPml informs you that you are excessing the limits. You have to change to a shallower depth -> 12 ENTER -> the eRDPml informs you that the Multilevel Limit is 87 minutes -> ENTER -> ABT? 18 -> the eRDPml informs you that you have to follow Rule 2 (3m safety stop) -> ENTER -> the eRDPml informs you that the Pressure Group after this dive is M.

5 Skills and Environment

- The CESA skills: It means Controlled Emergency Swimming Ascent; while performing it, a student has all equipment in place, ascends no faster than 18m/min, has the right hand above the head, the left hand on the deflate button on the LPI and he looks up making a continuous "*aaah*" sound, exhaling through the ascent.
- The **Buoyancy Check skill**: The diver, in water too deep in which to stand, should float at eye level while holding a normal breath and no air in his BCD.
- The **Exercise 7 skill** (See the Rescue Steps.pdf file):
  - In water, you cannot provide CPR, so you should follow these steps:
    - 1) Stop, Think, Act. Put your regulator in, make sure you are not in danger, call the diver to check for consciousness, and approach.
    - 2) Turn the body up, approach from the right (for an easy drop of the weight belt), establish positive buoyancy. Inflate both BCDs, drop both belts, take off both regulators, and take off both masks.
    - 3) Open Airways, check for breathing (look, listen, and feel) -> Call for help
    - 4) Give 2 rescue breathes
    - 5) Protect the airways and give one breath every 5 seconds
    - 6) Tow to shore or boat while removing equipment (breaths take priority).
- The Buddy-Check - B.W.R.A.F – Breakfast With Rice And Friends:
  - BCD, Weights, Releases, Air, Final OK (fins, mask, computer with right gas set).
- Compass navigation skill: Make sure the student has the arms in the right position, flat, and that they are not swimming upwards. To navigate:
  - On a reciprocal heading, rotate the bezel 180 degrees
  - On a square, turn 90 degrees
  - On a triangle, turn 120 degrees.
- The search and recovery skills:
  - Search patterns: U pattern search, Expanding square, Circular search pattern. When choosing the pattern, take into consideration: current, visibility, experience of divers, underwater topography, and size of the object.
  - Use a lift bag for objects that weigh more than 4 - 7 kg.
- Alternate air source should be in the triangle between chin and lower corners of rib cage.
- The Sea:
  - Waves are directly caused by wind and will start to break when the depth reaches 1.3 times the height of the wave
  - Tides are primarily caused by the moon and the sun
  - Oceanic currents are caused by wind direction and the rotation of the earth. This is known as the Coriolis Effect. (In the Northern Hemisphere, the currents move clockwise; in the Southern Hemisphere, the currents move counter-clockwise)
- Environment:
  - Be correctly weighted
  - Do not touch anything