**DIVE THEORY STUDY GUIDE** by Rod Abbotson CD69259 

Guidelines for studying:

Study each area in order as the theory from one subject is used to build upon the theory in the next subject.
When you have completed a subject, take tests and exams in that subject to make sure you understand everything before moving on.
If you try to jump around or don't completely understand something; this can lead to gaps in your knowledge.
You need to apply the knowledge in earlier sections to understand the concepts in later sections...
If you study this way you will retain all of the information and you will have no problems with any PADI dive theory exams you may take in the future.

Before completing the section on decompression theory and the RDP make sure you are thoroughly familiar with the RDP, both Wheel and table versions. Use the appropriate instructions for use guides which come with the product.

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**PHYSICS** **SECTION ONE**

**Light:**
The speed of light changes as it passes through different things such as air, glass and water. This affects the way we see things underwater with a diving mask.
As the light passes through the glass of the mask and the air space, the difference in speed causes the light rays to bend; this is called *refraction.*
To the diver wearing a normal diving mask objects appear to be larger and closer than they actually are. About 25% larger and closer by a ratio of 4:3. (If the object is actually 4m away it will appear only 3m away when viewed through a diving mask and 25% bigger).
*Turbidity* (Bad visibility underwater) can cause the diver to perceive (think) that objects are further away than they actually are because they obscured by particles in the water. This phenomenon is known as *visual reversal.*
As light hits the surface of the water the light waves are scattered in all directions this is why we get less light as we go deeper. The better the clarity of the water and the higher the angle of the sun the more light penetrates. (This is why photographers prefer to dive between 10.00am and 2.00pm).
Light is also *absorbed* as it travels through water; the shorter wavelengths disappear first which in the spectrum is red. So the *red* colors are the first to disappear and blue last.

**Sound:**
Sound travels *four times faster* in water than it does in air. This is because the water is a *denser* and more elastic medium than air. 800 times more dense.
Because of this the diver's brain perceives the sound as reaching both ears at the same time. This means he cannot tell the *direction* the sound is coming from. The sound seems to come from everywhere at once or overhead.
Although the dive cannot tell the direction he can tell whether the sound is either closer or further away depending on its volume. Sound can travel very long distances underwater.

**Heat:**
Water has a much higher *heat capacity* than air; this is its ability to draw heat away from another object such as a diver. Water conducts heat away from the diver *twenty times faster* than air for a given temperature. This is why a diver will chill quickly without an exposure suit even in warmer water.

The diver loses heat by three different methods while underwater.
The first method is *conduction* which has *most effect* on the diver; this is caused by the water drawing heat by direct contact with the diver or his suit.
The second method is *convection*; this is caused by the movement of the water around the diver.
The third method is *radiation* which has the *least effect* on the diver; this is caused by the diver radiating his body heat out to the water.

**Pressure:**
Pressure is measured in bars or atmospheres (atm), essentially the same.

Gauge pressure is the pressure of the water at a given depth.

Absolute or Ambient pressure is the water pressure plus the atmospheric pressure. (At sea level the atmospheric pressure is 1 bar/atm).

Pressure increases in sea water by 1 bar every 10 meters.

Pressure increases in fresh water by 1 bar every 10.3 meters.

To calculate gauge pressure in bar simply divide the depth of the water by 10 for seawater and by 10.3 for fresh water.

Examples…

To calculate the gauge pressure at 37m in sea water.

$37 \div 10 = 3.7$ bar.

To calculate the gauge pressure at 16m in fresh water.

$16 \div 10.3 = 1.55$ bar.

To calculate the absolute/ambient pressure in bar simply repeat the above procedure and then add 1 (providing you are calculating for sea level).

Examples…

To calculate the absolute pressure at 27m in sea water.

$27 \div 10 = 2.7 + 1 = 3.7$ bar.

To calculate the absolute pressure at 22m in fresh water.

$22 \div 10.3 = 2.14 + 1 = 3.14$ bar.

To calculate the ambient pressure at 40m in fresh water at an altitude where the atmospheric pressure is 0.7 bar.

$40 \div 10.3 = 3.88 + 0.7 = 4.58$ bar.

*Remember that in all questions in physics of diving (except if they just ask you for the gauge pressure) you will use absolute pressure in your calculations.*

**Pressure and volume:**

For all intents and purposes you cannot compress a liquid or a solid by applying greater pressure, but you can compress a gas as the molecules are further apart. Boyle's Law states that the volume of a gas is inversely proportional the surrounding pressure on the gas.

So it looks like this…. Volume = $\frac{1}{\text{Absolute Pressure}}$

Examples….

If you take an inverted bucket down to 20m what would the volume of the air be inside it?

Volume = ⅓

If a balloon contains 15 liters of air at the surface; what would its volume be if taken down to 40m?

15 ÷ 5 = 3 liters.

If a balloon contains 7 liters of air at 30m and is then taken to the surface; how much would its volume then be?

7 x 4 = 28 liters.

*Remember, with volume, multiply by the absolute pressure if you go up and divide by the absolute pressure if you go down.*

*If you move from one depth to another, it's easiest to take it first to the surface and then back down to the new depth.*

Example….

You take a balloon containing 5 liters of air from 35m up to 15m, what would its new volume be?

5 x 4.5 = 22.5 liters at the surface, then take it back down to 15m

22.5 ÷ 2.5 = 9 liters at 15m.

A balloon is sometimes referred to a *flexible container.* A scuba tank is referred to as an *inflexible container* – **a scuba tank does not change volume or the amount of air it holds when changing depth.**

**Pressure and Density**

Now it's all the other way around because as you squash the gas and make its volume smaller you increase its density – if the gas expands (when going up) then you decrease its density. What does this mean?
When calculating densities you divide when you go up and multiply when you go down. The opposite of calculating volumes. This comes into effect when calculating air consumption.

Examples….
A diver breathes 20 liters a minute at the surface; how much air would he breath per minute at 30m?
20 x 4 = 80 l/min     easy eh?

Look at the following question, this stumped many people on an instructor exam.

A diver breathes 70 bar of air in 10 minutes at 30m, he then ascends to 20m for 20 minutes, how much air will he consume at his new depth?

OK the question is in bar as he is using the same tank (this is not a tec question) we can calculate it in bar.
So first how many bar does he breath in one minute?
70 ÷ 10 = 7 bar/min at 30m
Now take it to the surface
7 ÷ 4 = 1.75 bar/min at the surface. Now take this back down to 20m.
1.75 x 3 = 5.25 bar/min at 20m. He stays there for 20 minutes so:
5.25 x 20 = 105 bar
Just break the question down into small steps and it is easy!

**Partial Pressures**
Dalton's Law states that in a mixture of gases that each gas exerts a pressure proportional to the percentage of that gas in the mixture. What does this mean to us as divers?
Air is a mixture of gases, for calculating purposes 21% Oxygen and 79% Nitrogen this obviously changes when using enriched air, custom deco mixes and trimixes. If you understand this you will have no problems with tec diving theory.
So let's look at air.
At the surface the pressure is 1 bar, air is made up of 21% oxygen and 79% nitrogen. So the oxygen is responsible for 0.21 bar and the nitrogen responsible for 0.79 bar. As we go deeper the partial pressure of the gases increases in proportion to the overall pressure but the *percentage remains the same*.

To calculate the partial pressure of a gas at depth divide the percentage of the gas in the mix by 100 and simply multiply by the absolute pressure at that depth.

Examples….
What is the partial pressure of Oxygen in Air at 30m?
21 ÷ 100 = 0.21 x 4 = 0.84 bar.

What is the partial pressure of Nitrogen at 25m with EANx32?
*(EANx32 has 32% Oxygen therefore 68% Nitrogen)*
68 ÷ 100 = 0.68 x 3.5 = 2.38 bar.

Another way a question can be asked appertaining to partial pressures and contaminated air is this:
If a diver breathes air containing 0.5% Carbon Monoxide at 30m it would be the same as breathing______ % Carbon Monoxide at the surface. In this case you multiply the equation out so…..
Simply 0.5% x 4 bar = 2.0%

This is correct but what you are actually doing is as follows…..
0.5 ÷ 100 = 0.005 partial pressure of CO at the surface (ppCO)
0.005 x 4 = 0.02 partial pressure of CO at 30m
0.02 x 100 = 2% convert back to percent. Giving you what this partial pressure would be expressed as a percent at the surface.

But if the question asks how many per cent CO the diver breathes at 30m the answer would be 0.5% the same as the surface. *Read the question!*

One question that stumped candidates recently on partial pressure when like this…
What would be the approximate partial pressure of Nitrogen in air if breathed at altitude where the ambient pressure was 0.7 atm.
Simple!
79 ÷ 100 = 0.79 x 0.7 (the absolute pressure in this case) = 0.556 bar
The actual answer was 0.56 but it was multi choice so this would be the nearest answer. Because the question asked approximately they had assumed 80% Nitrogen in the air so 0.8 x 0.7 = 0.56.

**Pressure and Absorption of Gases**
Although this could be a complex subject being the mechanism behind DCS, dive table and computer algorithms; for PADI exams it is only the simple basics of Henry's Law you need to know.
If the pressure of a gas in contact with a liquid is increased the gas will dissolve into the liquid until a state of equilibrium is reached. *(Saturation).*
If the pressure of a gas in contact with a liquid is decreased the gas will come out of the liquid *(supersaturation)* if this happens quickly bubbles will form in the liquid.
*Remember the opened shaken soda can or* ***your blood if you forget stops or come up to quickly.***

**Pressure, Temperature & Volume relationships**

This is Charles's Law but we'll go into that in a minute if you are interested; for PADI they make it simple to keep it easy for you.
So first let's look at temperature and pressure, this would apply to an inflexible container such as a scuba tank.

For every degree celcius change the pressure changes by 0.6 bar.

If the temperature increases, the pressure increases.
If the temperature decreases, the pressure decreases.

Examples…

A scuba tank is filled to 200 bar at 15 degrees celcius, it is then left in the sun at a temperature of 30 degrees celcius – what would the pressure in the tank now be?

30 – 15 = 15 degrees change
15 x 0.6 = 9 bar change upwards
New pressure = 209 bar.

Or a scuba tank is filled to 210 bar at a temperature of 35 degrees C and is then taken into water of 5 degrees C what would the pressure in the tank now be?

35 – 5 = 30
30 x 0.6 = 18
210 – 18 = 192 bar.

Now let's look at temperature and volume this applies to flexible containers or balloons in the questions as in this case the pressure remains the same and the volume changes.

For PADI exams you don't need to know by how much just bigger or smaller!!

OK Nice and easy a balloon taken out of a fridge and out in hot air will increase in volume AND a balloon filled in hot air and place into a fridge will decrease in volume. THAT'S IT.

***USE THE ABOVE FOR PADI EXAMS***

**Skip the next section if all the math confuses you, if you want to know how Charles's Law really works – read on**.

*The formula is simple and looks like this*

$$\frac{P1 \times V1}{T1} = \frac{P2 \times V2}{T2}$$

*Where P = pressure, V = volume and T = temperature*
*SI units must be used pressure in bar volume in liters and temperature in degrees Kelvin. (Absolute temperature).*

*When there is no temperature at all it is zero degrees Kelvin. This is equal to minus 273 degrees celcius. So if the problem gives temperatures in celcius we have to convert to degrees Kelvin by simply adding 273.*

*So let's look at that tank question again take the one where the tank is filled to 210bar at 35 degrees C and taken to 5 degrees C in cold water. Remember the PADI exam answer was 192bar. Let's calculate this exactly.*

*As the volume doesn't change we can take this out of Charles's formula this leaves:*

$$\frac{P1}{T1} = \frac{P2}{T2}$$

*if we put the figures in it looks like this:*

$$\frac{210}{308} = \frac{P2}{278}$$

*we want to find the value of P2 so we multiply both sides of the equation by 278 this then gives us:*

$$P2 = \frac{210 \times 278}{308} = \frac{58380}{308} = 189.54 \text{ bar}$$

*Around 2.5 bar less than the PADI answer, so don't use this formula in a PADI exam, the examiners don't like clever clogs! Besides the answer will be wrong according to their answer key and you can't argue or you get kicked out of the exam!!*

*To continue with Charles's Law, what about the balloon and the fridge…..*
*As PADI doesn't use Charles's Law in the exams you cannot get a question like this, but you could work it out.*

*Example. A balloon containing 10 liters of air at a temperature of 25 degrees celcius is put into a fridge at just 4 degrees celcius, what would its new volume be?*

*As the pressure remains the same the formula now looks like this:*

$$\frac{V1}{T1} = \frac{V2}{T2}$$ *with the figures in* $$\frac{10}{298} = \frac{V2}{277}$$

*Contract the formula and it looks like this* $V2 = \frac{10 \times 277}{298} = 9.29$ *liters.*

*A good one to ask a new PADI Instructor!!*

*Ignore that last section on Charles's Law for PADI exams.*

*Now let's get back to PADI theory….*

**Buoyancy**

A diver once commented to me, after a dive where they lost control of their buoyancy towards the end of the dive (not dumping air soon enough and drifting up to the surface!), "My buoyancy just went!" If that was the case he would have sunk like a stone! It is the one thing that many novice divers don't understand properly, if they did it would probably cut out many accidents.

Archimedes's Principle states: "Any object immersed in a fluid is buoyed up by a force equal to the weight of fluid displaced by the object".

OK let me translate that into diving the fluid is going to be water either fresh or salt(seawater). The object will be a diver or something that the diver wants to lift with a bag or sink with weights. To do this we usually want to make the object neutrally buoyant (so the object being lifted doesn't shoot to the surface or the diver doesn't sink uncontrollably!

There is a really cool formula to calculate this:

$$\frac{\text{Object weight (in kgs)}}{\text{Weight of 1lt of water}} - \text{Displacement (in liters of water)} = \text{lift (in liters of air)}$$

This is simple in fresh water as one liter of fresh water weighs 1kg

Example: How much air do you need to add to a lifting bag to make an anchor weighing 75 kgs and displacing 15 liters of water? It is lying in 14m of fresh water.

75 – 15 = 60 liters easy but what if the question said it was in seawater?

One liter of seawater weighs 1.03 kilograms (don't argue this is according to PADI we all know it's really 1.028 – ask any ship owner!) So the equation now looks like this.

(75 ÷ 1.03) -15 = lift

72.82 -15 = 57.82 liters

Easy if you have a calculator, if you don't look for the answer that's less than the fresh water answer. (If there are two like this you need a calculator!)

Some new questions have come up in the Divemaster exams which caused some confusion at first – divers told me that the formula didn't work. Of course it does! Remember you can't mix apples and oranges, or liters and kilos.
Example: How much lead would you need to add to an object that weighs 90 kgs and displaces 100 liters to make the object neutrally buoyant in seawater.

(90÷1.03) = 87.4 - 100 = -12.6 this is a negative amount of liters of seawater you need to displace, how much does 12.6 liters of seawater weigh in kilos? Easy 12.6 x 1.03 = 12.98 kgs.
So if this was a diver you would have to stick 13kgs on his weightbelt.

So here is something interesting you can do.

1) Stand on a scale in full equipment and weigh yourself (no weightbelt)
2) Do a buoyancy check and find out how much weight you need to make you neutrally buoyant.
3) Assuming you did the check in the pool, calculate how much freshwater you displace with full kit.
4) Now you can work out exactly how much more weight you will need in the sea!

Let's take an example say you weigh 80 kgs add all your dive gear to that and you will weigh around 110 kgs; you jump in the pool and find that you need 6 kgs of lead to be neutrally buoyant. This means you were displacing 116 liters of fresh water. So let's put that into the formula:

(110÷1.03) = 106.8 – 116 = -9.2 liters of seawater, so 9.2 x 1.03 = 9.5kgs.

So this imaginary diver would have added another 3.5 kgs to his weightbelt to be neutrally buoyant in the sea!!
An interesting exercise – but always do a proper buoyancy check.

Now try to work out how much volume you suit loses when it compresses and calculate how much air you need to add to you BCD for a given depth. Then you can work out what size BCD bladder you need and how deep you can go before you can't gain neutral buoyancy.
Eg. If the suit displaces 10 liters of water you would need to add about 7.5 liters of air to your BCD at 30m in fresh water.

If an object is neutrally buoyant in salt water it will sink in fresh water.
If an object is neutrally buoyant in fresh water it will float in salt water.

If an object is positively or negatively buoyant in either fresh or salt water you cannot determine exactly what will happen when placed from fresh to salt or vice versa. So read the question carefully.

## PHYSIOLOGY SECTION TWO

Please make sure that you have read and understood the “Physics” section before starting on this one, as the information builds up in sequence.

Knowing the information in this section is very important to the PADI professional so that you can understand exactly what is happening to you and your divers/students whilst you are underwater.

### Circulation:

Blood circulates around your body to fuel the body with Oxygen, the body uses the Oxygen and changes it to Carbon Dioxide ($CO_2$) the blood then carries this back to the lungs where $CO_2$ is released and more Oxygen taken on. This whole process is known as “*oxidative metabolism*”.

The blood is made mainly of plasma, a clear fluid, red blood cells which give it the color, white blood cells which fight off infection and platelets which help the blood to clot in case of injury.

The *red blood cells* carry the *oxygen* which combines with *hemoglobin* in the cells. Red blood cells are also known as *“erythrocytes”.*
The waste *$CO_2$* is carried away in the *plasma*, dissolved as *bicarbonate.*

All this is pumped around by a four chambered pump, the heart. Blood vessels carrying blood away from the heart are called *arteries*. (This is why they spurt out blood rhythmically when punctured as it is pressurized.) Blood vessels carrying blood back to the heart are called *veins*. In between the arteries and veins are small blood vessels where the tissues take on Oxygen and release $CO_2$ these are called *capillaries*.

Let’s look at the route in sequence, starting at the lungs where the blood releases $CO_2$ and takes on oxygen at the *pulmonary capillaries.*

The newly oxygenated blood is pumped back to the heart by the pulmonary vein and is in turn pumped out through the body via the arteries. These get smaller and smaller until they become capillaries where the oxygen is taken on by the body tissues and the waste $CO_2$ released. The $CO_2$ is converted to bicarbonate and carried back in the plasma part of the blood via the veins back to the heart. It is then pumped via the pulmonary artery back to the lungs for re-oxygenation at the pulmonary capillaries, which is where we started.

**Respiration:**

To get the oxygen to the *pulmonary capillaries* we need to breathe, this is called respiration. To trigger this in the body the build up of CO2 causes the *diaphragm* to flex downward making us exhale an inhale again. (If you don't believe me try holding your breathe for as long as you can and see what happens to your diaphragm!)
The air passes through the nose which filters the air and the sinuses moisturize the air before it reaches the lungs, when breathing through your mouth, as in diving, this step is bypassed; this is one of the reasons breathing has to filtered and why you get dehydrated when diving – always drink plenty of water.
The air then enters the *trachea* via the throat and into the *bronchi*, which are large tubes leading to the lung. These split into smaller and smaller *bronchioles* until reaching the *alveoli*; small sacs surrounded by the *pulmonary capillaries* where the gas exchange takes place through a thin membrane.

For maximum gas exchange you need to breathe *slowly and deeply*. When you exhale some of the stale air remains in your lungs and passages to the lungs; this is re-inhaled on the next breath.
These are known as *dead air spaces* as no gas exchange can take place here; snorkels and regulators increase dead air space. Shallow, rapid breathing also creates turbulence in the air passages so not as much reaches the alveoli. This causes a build up of carbon dioxide, known as hypercapnia, which makes the diver feel out of breath. This can also be caused by the diver overexerting himself or a badly maintained regulator which is difficult to breathe from.

**Apnea:**

This is simply breath hold diving. When you hold your breath and dive you use the oxygen stored in the tissues, when the waste CO2 builds up the urge to breathe becomes intolerable and the diver is forced to surface to breathe again and replenish the cells with oxygen.
If the diver *hyperventilates* before the breathe hold dive this reduces the residual CO2 in the lungs and extends the time before the diver gets the urge to breathe. A maximum of *3-4* deep breathes is OK. But any more and this is what happens:

*Excessive hyperventilation* reduces the CO2 levels in the lungs too much (hypocapnia), so that when the diver is underwater the oxygen level drops below critical levels before the CO2 creates the urge to breath. While the diver is at depth, the partial pressure of the oxygen is greater (remember the physics), when the diver ascends the *partial pressure of the oxygen drops* below the critical level to sustain consciousness; the diver blacks out before reaching the surface due to *hypoxia* (lack of oxygen). This phenomenon is known as *shallow water blackout* and only happens when the diver ascends.

Also in cold water when performing a breath hold dive, bradycardia (slowing of the heart), reduces circulation speed. This is much more evident in marine mammals than humans, although some free diving experts claim to be able to control this. Remember Jacques Mayol in the Big Blue.

**Carotid Sinus Reflex:**

The carotid sinus receptors monitor the pressure of arterial blood reaching the brain through the carotid arteries.

Low blood pressure triggers a higher heart rate *(tachycardia).*
High blood pressure triggers a lower heart rate *(bradycardia).*

Receptors will interpret the pressure from an excessively *tight hood*, wet suit neck seal or dry suit neck seal as high blood pressure.

This *reduces blood flow to the brain* as the heart slows causing the diver to feel light headed if this continues it can lead to unconsciousness.

**Carbon Monoxide poisoning:**

This is caused by contaminated air from using the wrong lubricants or improper maintenance of the compressor system. Smoking is another source of carbon monoxide, it takes *8-12* hours to flush the CO from you body after smoking just one cigarette!! Smoking also destroys the *surfactant* in you lungs. This is the lubricant that prevents the walls of the airways in the lungs from sticking together. If this happens you could have a lung over expansion injury without ever holding your breath!!
Carbon monoxide bonds with the hemoglobin *200 times more readily* than oxygen but doesn't release as easily. When air contaminated with CO is breathed at depth the hemoglobin carries less and less oxygen as the CO bonds with it. However, at depth, the blood still carries enough oxygen dissolved in the plasma by the high partial pressure to meet tissue demands.
As the diver ascends and surfaces the plasma cannot carry enough oxygen and the diver blacks out due to *hypoxia.*
Signs and symptoms include headache, confusion, narrow vision, *bright red lips and fingernail beds*. Give Oxygen and get to medical care.

**Oxygen Toxicity:**

If you dive on air to greater than 57m or much shallower when using enriched air nitrox mixes. You can have problems with the high partial pressure of oxygen.

There are two types:

1) Central nervous system (CNS) toxicity – caused by exposure to oxygen partial pressures greater than *1.4 bar*. (57m on air, 33m on EANx32, 29m on EANx36 and just 4m on pure Oxygen.
   Signs and symptoms include: visual disturbances, ear ringing, nausea, twitching, irritability and dizziness. But the *most serious symptom/sign is a convulsion usually without warning* which can cause the diver to lose his mouthpiece and drown.

2) Pulmonary toxicity – caused by a long exposure to high partial pressures of oxygen. Usually only occurs after a series of multiple dives using enriched air or in technical diving using high concentrations of oxygen for long decompression schedules.
   Signs and symptoms include burning in the chest and an irritated cough.
   It usually resolves itself if the diver ceases diving for a few days.
   It is avoided by following NOAA and DSAT oxygen exposure tables.

**Nitrogen Narcosis:**

Almost any gas can cause a narcotic effect under pressure.
It appears to be related to nerve impulse blockage due to gas dissolved in the nerves.
Oxygen has about the same potential so don't expect to be less susceptible when using Nitrox mixes.
Expect narcosis to be noticeable at *around 30m*, it varies from one diver to the next and is not predictable.
Helium is not narcotic under high pressures which is why it is used in deep technical diving.

*Ascending a few meters* usually relieves the symptoms which are not directly hazardous – the danger comes from *impaired judgment and co-ordination* which may lead to bad decisions.

Other symptoms can included euphoria (feeling happy), anxiousness, panic, dizziness, tunnel vision.

**Decompression sickness:**

When under pressure gases will dissolve into liquids, our body is mostly water so when we breathe air at depth it goes into solution in body tissues.

Oxygen is consumed metabolically, but nitrogen is physiologically inert and dissolves into the blood and tissues.

This dissolved gas still exerts pressure which is known as *tissue pressure*. Different tissues absorb and release nitrogen at different rates.

If the diver stays at depth eventually his body will *saturate* meaning the gas pressures have reached an equilibrium and he can't absorb any more nitrogen.

Calculating different tissue absorption and release is the basis of decompression models for tables and computers.

Recreational dives are too short to reach saturation, but upon ascent from any dive the nitrogen pressure in the tissues is greater than the surrounding pressure, this is called *supersaturation.*

If the difference between the tissue pressure and the surrounding pressure *(the pressure gradient)* is kept within limits the nitrogen dissolves harmlessly out of the body through respiration.

After some dives *Doppler ultrasound flowmeters* detect *silent bubbles* in divers – *these are harmless* in themselves but could join up to form larger bubbles if there's too many of them.

If the diver ascends too quickly or misses required decompression stops these small bubbles accumulate and form larger bubbles causing decompression sickness (the bends).

Signs and symptoms depend on where the bubbles form.

Type 1 DCS pain only usually in the joints and limbs and skin bends (rashes on the shoulders and upper chest).

Type 2 DCS life threatening involving the nervous system, numbness, tingling, paralysis, weakness, fatigue, unconsciousness and death.

There are several physiological factors that may predispose a diver to DCS, In other words make it more likely he will get bent even when sticking to tables or a computer especially if near the limits.

These are:

- Fat tissue: Fat releases nitrogen slowly so a fat diver may have more nitrogen after a dive.
- Age:  As we get older our circulatory systems become less efficient slowing down the gas exchange.
- Dehydration: This reduces the blood in circulation, slowing nitrogen elimination. Always drink plenty of water while diving.
- Injuries/illness: These could alter or restrict circulation to localized areas where nitrogen isn't eliminated as quickly.
- Alcohol before or after diving: This alters circulation patterns, dilates capillaries and promotes dehydration, all of which alter nitrogen elimination and bubble formation.
- Carbon Dioxide excess: Raised $CO_2$ levels will alter circulation and gas exchange.
- Cold Water: When the diver gets cold circulation to the extremities is reduced hindering nitrogen release.
- Heavy Exercise: During the dive this can raise $CO_2$ levels and accelerate circulation so more nitrogen is absorbed. After a dive it accelerates circulation altering nitrogen elimination.
- Altitude/Flying: Tables and computers are based on surfacing at sea level, if we go to altitude after a dive this increase the pressure gradient and bubbles may form – returning to sea level will not alleviate the bubbles once formed!

Treatment for DCS

First aid   Treat all cases as serious, give the patient oxygen, keep the patient lying level on the left side with the head supported, provide primary care and arrange transport to the nearest medical facility.

**DCI** stands for decompression illness and covers all injuries caused by a rapid ascent or coming up too soon.

**DCS** refers only to the condition caused by dissolved nitrogen in the system.

**Heat and Cold:**

Overheating can cause problems. First *heat exhaustion* where the body works at full capacity to cool. Signs and symptoms include: weak rapid breathing, *weak rapid pulse, cool clammy skin, profuse sweating*, dehydration and nausea. Treatment is to get the diver to a cool area, remove exposure suit, and give nonalcoholic fluids, rest until cool.
Second *heat stroke*, if heat exhaustion is not treated promptly it can lead to heat stoke which is *life threatening*. The body's cooling system has now completely failed. Signs and symptoms include: *strong rapid pulse, no perspiration, skin flushed, hot to touch*. Treatment: Cool by whatever means available and get the diver to emergency medical care.

The body responds to heat loss by *vasoconstriction* (reduced blood flow to the extremities) causing finger and toe numbness. Then *shivering* as the body tries to generate heat by muscle movement. This signals a losing battle against the cold and is termed *mild hypothermia*. Get the diver to a warm place as soon as possible. If heat loss continues the condition gets worse; *advanced hypothermia*. Shivering stops. Vasoconstriction stops. The diver may feel warm as blood rushes to the skin. The core temperature drops, mental processes slow, the diver becomes drowsy, then unconsciousness, coma and death. Advanced hypothermia requires *emergency medical care* as soon as possible.

**The Ear:**
The ear is divided into the outer, middle and inner ear.

- The *outer ear* consists of the external ear and ear canal, it is open to air/water pressure and channels sound to the eardrum.
- The *middle ear* is separated from the outer ear by the *ear drum* and is sealed against air/water. The ear drum vibrates and passes sound to the *ossicles,* small bones that conduct sound to the inner ear.
- The *inner ear* consists of the *vestibular canals* that control *balance* and the *cochlea* which turns vibrations into nerve impulses sent by the auditory nerve to the brain.
- The ossicles connect to the cochlea at the *oval window* which flexes in and out with the vibrations. The *round window* on the cochlea flexes out when the oval window flexes in, like a water filled balloon.

The middle ear is connected by the *Eustachian tube* to the throat to maintain equilibrium with outside pressure.

As the diver descends pressure pushes in on the eardrum causing discomfort, by equalizing the diver forces air up the Eustachian tube to equalize pressure in the middle ear alleviating the discomfort. Expanding air normally exits from the middle ear through the Eustachian tube easily on ascent.

If the diver does not equalize sufficiently hydrostatic pressure forces blood and fluid into the middle ear until equilibrium is restored. The ears feel full and hearing is reduced – should be checked by a doctor. This is called ***middle ear squeeze.***

If the diver does not equalize and descends faster than fluids can fill the middle ear the eardrum tears due to the pressure. The diver feels a sharp pain, and then relief as the pressure is relieved. When cold water enters the middle ear the diver will experience dizziness or vertigo until the water warms to body temperature. This is because is causes convection in the fluids of the vestibular canals effecting balance.

If the diver delays equalization, then tries to equalize *forcefully using the Valsava maneuver* (blowing against pinched nostrils from the diaphragm and lungs) pressure on the ear drum presses in on the ossicles which press in on the oval window on the cochlea; the round window flexes out in response. The Valsalva maneuver raises pressure in the chest, which causes an increase in pressure in the cochlea (connected by fluid as part of the nervous system). This, plus the transmitted pressure bursts the round window outwards.
This is serious and requires medical treatment; the diver may never be able to dive again! To avoid this always use the *Frenzel maneuver* (blowing against pinched nostrils but just using the throat muscles to push the air up the Eustachian tube). Bet that's the way you do it anyway!
This injury is known as **round window rupture.**

If the air cannot escape from the middle ear through the Eustachian tube on ascent a phenomenon known as **reverse squeeze** occurs. This is usually caused by diving with a cold or using a decongestant that has worn off. Stop or slow ascent and wait for trapped air to work its way out. Swallowing may help or inhaling against pinched nostrils. If ascent continues the eardrum will rupture outward.

Earplugs or a tight wet suit hood create an air space between the plug/hood and the eardrum. When the diver descends the eardrum flexes out towards the plug/hood and can rupture if descent continues. Feels like middle ear squeeze. Avoid by never wearing earplugs and pulling away hood momentarily when equalizing on descent.

Let's have some definitions before we continue….

**Barotrauma** means pressure injury. Baro = pressure. Trauma = injury.
It can happen on descent or ascent if an air space is not equalized.
An unequalized air space is also called **a squeeze.**

**Other air spaces:**

**Sinuses** are spaces in the head connected to the nose that filter and moisturize air before it reaches the lungs. They normally equalize with the ears with no problems. Sinus squeeze is usually caused by diving with a cold or congestion. The unequalized sinuses fill with blood and fluid to equalize during the dive – may feel like a sharp pain above the eyes. Upon ascent expanding air pushes blood and fluid into the nasal cavity and the diver surfaces with blood in his mask. This is usually not serious and heals on its own.

**Mask space:** This normally equalized by the diver exhaling into the mask during descent. (That is why you can't dive using goggles). If this is not done the tissues swell, forced into the unequalized mask space, capillaries in the skin and eyes rupture. Looks terrible but usually clears by itself.

**Dry suit space:** Squeeze can be caused by not adding enough air to the suit or descending too quickly. Can constrict breathing and caused welts and pinches where the dry suit squeezes.

And finally the biggest air space:

**The lungs:**

**Lung squeeze** is caused by a breath hold descent that reduces lung volume below the residual volume. (This would happen if you went down to over 30m on a breath hold dive). It can occur shallower if you descend with partially full or empty lungs. It causes fluid to accumulate in the lungs and can be life threatening – remember Enzo in the Big Blue. Not likely in recreational diving.

**Lung over expansion injuries:**

This what happens if you hold your breath on ascent when using scuba. They can also be caused by lung congestion if diving with a chest cold, or by a local blockage due to loss of surfactant due to smoking.
There are four types of injury that can occur.

**Air embolism:** This is also called arterial gas embolism (AGE). The alveoli and pulmonary capillaries rupture allowing air to enter the bloodstream and flow into the arteries. This is serious and immediately life threatening, the bubbles can lodge anywhere, but usually flow through the *carotid arteries straight to the brain* causing stroke like symptoms, dizziness, confusion, shock, paralysis, personality change, unconsciousness and death..

With all lung over expansion injuries always expect *air embolism* as this is the worst case scenario, it often occurs with the other types of lung injury.

**Pneumothorax:** The air from the rupture goes between the lung and chest wall, causing the *lung to collapse*. Also serious the diver will have chest pain and may cough up blood.

**Mediastinal emphysema**: The air from the rupture accumulates in the *center of the chest over the heart* and interferes with circulation; the diver may feel faint and short of breath, still serious.

**Subcutaneous emphysema**: The air from the rupture accumulates in the soft *tissues at the base of the neck*. The diver's voice may change and the skin may crackle to the touch.

First aid treatment for these injuries is the same as for DCS, hence the common term DCI to encompass both types of injury.
Lie the patient down and administer oxygen, apply primary care and get to a medical facility ASAP.

Note that symptoms of lung over expansion injury usually occur immediately after the dive whereas symptoms of decompression sickness are delayed and can appear 15 minutes after surfacing or even up to 24 hrs before the diver notices symptoms. Micro bubble maximums occur around 35 -40 minutes after surfacing this is the time when most bends will become apparent. But remember this is not an exact science.

**The Haldanean Decompression Model:**

Virtually all dive tables and dive computers calculate no decompression limits and decompression stops (when needed) based on a *Haldanean decompression model.*
This is named after John Scott Haldane who developed the first such mathematical decompression model and based on it the first dive tables in 1906.

Modern decompression models are based on the same ideas.

When the diver descends to a given depth, the nitrogen pressure in his breathing air is higher than the nitrogen *tissue pressure* in his body, so more nitrogen dissolves into the body tissues.

With enough time the nitrogen pressure equalize and the body cannot take on any more nitrogen. This is called saturation.

When the diver ascends the nitrogen *tissue pressure* in the body becomes higher than the nitrogen pressure in his breathing air, causing the tissues to release nitrogen to equalize the nitrogen pressure again.

The difference between the dissolved nitrogen tissue pressure and the nitrogen pressure in the breathing air is called the *pressure gradient*. Whether the diver is descending or ascending.

When the diver ascends the tissues can tolerate some gradient of high tissue pressure without causing decompression sickness.

If the *pressure gradient* exceeds acceptable limits, bubbles may form and cause decompression sickness.

Decompression sickness can be avoided by keeping the gradient within acceptable limits.

This means the diver must stay within the limits dictated by his table or computer and maintain a slow ascent rate as indicated by his tables or computer.

Haldane discovered that different parts of the body absorb and release dissolved nitrogen at different rates.

To account for these differences he constructed a model consisting of five theoretical tissues.

**These theoretical tissues do not directly correspond to any particular body tissue** so they are called compartments or tissue *compartments*.
The **RDP** has **14** compartments.

Each compartment has a *halftime* for the rate at which it absorbs and releases nitrogen.

Halftime is the time, in minutes, for a compartment to go halfway from its beginning tissue pressure to complete saturation.

After one halftime the tissue would be 50% saturated

After two halftimes the tissue would be 75% saturated

After three halftimes the tissue would be 87.5% saturated

After four halftimes the tissue would be 93.75% saturated

After five halftimes the tissue would be 96.875% saturated

After six halftimes the tissue would be 98.4375% saturated

It would never reach 100% using the halftime concept, so after *six halftimes the tissue compartment is considered full or empty.*

Haldanes original halftimes ranged from 5 to 75 minutes.

The RDP's halftimes range from 5 to 480 minutes split over 14 compartments.

They are 5, 10, 20, 30, 40, 60, 80, 100,120, 200, 240, 300, 360 and 480 minutes.

Sometimes tissue pressure is expressed in meters of seawater (gauge) msw.

Example: A 5 minute halftime compartment will have a tissue pressure of 9msw after 5 minutes in 18meters of seawater.

Example: A 20 minute halftime compartment will have a tissue pressure of 18msw after 40 minutes in 24m of seawater.

Example: A 60 minute halftime compartment will take 360 minutes (6 hours) to saturate to a given depth. (60 x 6 halftimes).

Besides different halftimes each compartment has a different *M-value.*

This is the maximum tissue pressure allowed in the compartment when surfacing to prevent exceeding the acceptable gradient.

There are actually different M-values for each compartment at different depths, these are used to calculate decompression schedules. *In no decompression diving we only use the one that applies to the surface*

The *slower* the compartment, the *lower* the M-value.

The *faster* the compartment, the *higher* the M-value.

The M-value is determined by test dives showing what does and what does not result in Doppler detectable bubbles.

Remember that the M-values are calculated for surfacing at sea level which is why you need to apply special procedures when diving at altitudes above 300m.

When any compartment reaches its M-value the dive ends or it becomes a decompression dive.

On deeper dives faster compartments will reach there M-values first, hence deeper dives have short no decompression limits.

On shallower dives, the depth is not enough for the faster compartments to reach there M-values. Therefore a slower compartment controls the dive and the model allows more no decompression time.

The compartment that reaches its M-value first is called the *controlling compartment.*

These models are mathematical extrapolations; there is no ***direct*** relationship between the decompression model and the human body. This is why divers learn that there is always some risk of DCS even within table/computer limits and are asked to dive conservatively within the limits.

The actual risk of getting DCS within the limits is 0.04% - so don't panic and hang up your fins!

**US Navy tables:**

The first dive tables to be widely used and adapted to recreational diving where the U.S.Navy tables designed in the 1950's.

Six compartments were used with a slowest halftime of 120 minutes.

While at the surface all compartments would lose nitrogen at different rate depending on their halftime. Any compartment could control a repetitive dive, depending on the first dive, the surface interval and the second dive.

To solve this problem the U.S.Navy designed its surface interval credit on the worst case scenario, the slowest compartment (120 mins). This is why it takes 12 hours (720 mins. 6 x 120) to be "clean" when using their tables.

These tables were tested with US Navy divers, subjects were all male in their 20's and 30's and reasonably fit. The test criteria were bends/no bends.

**The Recreational Dive Planner (RDP):**

In the mid-1980's, Dr. Raymond Rogers recognized that the USN tables were not ideal for recreational diving.

The 120 minute half time used for surface interval credit, while appropriate for decompression diving seemed excessively conservative for recreational divers making only no decompression dives.

The test group the USN used didn't reflect recreational divers who include females and people of all ages.

New technology in the shape of Doppler ultrasound flow meters had come into being ; these showed that silent bubbles often formed at USN table limits, suggesting lower M-values would be more appropriate for recreational divers.

With the help of DSAT (Diving Science & Technology), Rogers developed the RDP. It was tested in 1987/88 at the Institute of Applied Physiology & Medicine with Dr. Michael Powell as the principal investigator.

A 60 minute gas washout tissue was used. Multi level diving was tested. Big range of test subjects, like recreational divers. Limited to Doppler detectable bubbles instead of bends/no bends. Tested to the limits for 4 dives per day for 6 days. Though more conservative diving practices are recommended.

Dr. Rogers found that the old 120 minute gas washout tissue was too conservative for recreational diving and adopted a 60 minute gas washout tissue. This means you get twice as much credit for surface intervals and are clean in 6 hours. The WXYZ rules make sure the slower compartments stay within limits. Dr. Rogers also lowered the M-values to match recent Doppler data. These are sometimes called Spencer limits after the physician who first proposed them.

They produced different versions of the RDP…
The table version, (because that's what divers were familiar with) and the multilevel electronic planner eRDPML version (originally the Wheel), to enable you to calculate multi level profiles.
DSAT have also produced four tables for enriched air diving.
Tables for using EANx32 and EANx36 an Equivalent air depth table and an Oxygen exposure table.
The pressure groups from all versions of the RDP are interchangeable.

**You cannot use RDP pressure groups with other tables.**

**Dive Computers:**

Dive computers offer maximum bottom time by essentially writing a custom dive table for the dive undertaken – this eliminates unnecessary rounding and therefore gives more dive time.
There are essentially 5 different groups of models or algorithms used in the many computers available to the recreational diver. This will normally be described in the instruction book for the particular computer. They are being developed all the time with diver safety in mind as more research is done.

1. Spencer limits, EE washout
    - Same M-values as RDP
    - All compartments release Nitrogen at the surface at their underwater halftime rates.
    - Can permit dives that are beyond what is safe, i.e. short deep repetitive dives with short surface intervals.

2. Spencer limits, 60 minute washout
    - Based on data for the RDP
    - Dives similar to what the RDP allows.

3. Buhlmann limits, EE washout
    - Further reduced M-values
    - All compartments release Nitrogen at the surface at their underwater halftime rates.
    - Because of the reduced M-values similar to what the RDP data supports despite the EE washout.

4. RGBM  (Reduced Gradient Bubble Model) and others.
    - Research is providing lots of new information on the behavior of divers and micro bubble build up.
    - Most dive computer models take this into account
    - If a diver exceeds a safe ascent rate on one dive he will be penalized on repetitive dives, the same with yoyo profiles.
    - Some take the water temperature into account and adjust accordingly.
    - Nearly all have altitude settings and settings for conservatism.
    - Some are integrated with air supply and take the divers breathing rate into account.
    - Nearly all models now support Nitrox diving.
    - Some support gas switch extended range and technical diving.
    - Some support trimix and CCR diving.

But remember the computer doesn't get bent, only you do, it's what the diver actually does that counts. **KNOW WHEN A COMPUTER IS GIVING YOU BULLSHIT!**

**PADI Recommendation for Diving with Computers:**

- Divers should not attempt to share a dive computer.
- Each diver must use the same computer through a series of dives.
- Each diver must have his own computer.
- Computers have the same theoretical basis as tables so one is neither better or safer than the other.
- All standard guidelines apply, such as deepest dives first.
- Follow all manufacturers recommendations.
- End the dive based on the most conservative computer of a buddy team (you're supposed to stick together anyway)!
- If a computer fails whilst diving ascend slowly to 5m and make a long safety stop as long as your air supply permits. You should then remain out of the water for 12 – 24 hours, so you can start clear again with another table or computer.
- Make sure it is capable of altitude diving if diving at altitude.
- Do not lend you computer to another diver if either of you have been diving.
- Do not use a computer from another diver if either of you have been diving.
- Do not try to change the battery between dives or underwater.
- If it caters for mixed gas make sure it is set to the gas you are using.
- Do not use the computer if it is displaying any error or not functioning correctly
- When you turn your dive computer on, do not turn your brain off, after all the latter is a better computer!

**Scuba Cylinders:**

All scuba cylinders have markings stamped at the neck. These will include, regardless of the country of manufacture, the following:

- Alloy designation (the metal type the cylinder is made from).
- Hydrostatic test date
- Working pressure
- Manufacturer's name
- Serial number

Some cylinders will have other markings depending on the country of origin.

- Water capacity
- Test pressure
- + mark to indicate it can filled to10% more than its working pressure
- Volume of air held at the working pressure
- Distributor's name
- Visual inspection stamp
- Batch number

Cylinders used for gases other than air should be clearly labeled as such. Some countries require certain color codes on the paint work to indicate this.
In recreational and technical diving you will come across the following.

Enriched Air Nitrox cylinders color coded clearly green and yellow, a label should indicate the percentage of oxygen in the mix. Up to 40% for recreational divers and up to 100% for technical divers.
In the latter case they will probably be also labeled as deco mix.

Argon cylinders are used for dry suit inflation and should be clearly marked as such. These are never used to breathe from as you would die.

Cylinders used for Trimix are usually marked with the oxygen content followed by the nitrogen content – the remaining content being helium.

All cylinders use for enriched air and technical diving should have clearly labeled maximum operating depth. MOD. Or in the case of Trimix, Helitrox, Heliair or Heliox a minimum operating depth above which there is not enough oxygen to support life.

Breathing the wrong gas at the wrong depth results in **DEATH.**

**All cylinders subject to partial pressure blending or used with more than 40% Oxygen should be oxygen clean, and the valves should be oxygen clean and oxygen compatible.**

**Failure to observe this rule can lead to fire and/or explosion leading to death or serious injury.**

Virtually all scuba cylinders are made from steel or aluminum alloys.

Steel is stronger than aluminum for the same thickness, so steel tanks have thinner walls and larger internal volumes for a given external size.

Aluminum's advantage is that it less subject to corrosion, you will find aluminum cylinders at most resorts.

Steel cylinders are heavy in the water and therefore you need less lead on your belt. They also have rounded bottoms and need a rubber boot to stand up.

**Cylinder testing:**

Hydrostatic testing (pressure test) must be carried out periodically as required by the law of the country you are diving in. In the USA and UK a hydrostatic test is required every five years.
The general procedure for the test is as follows:

- The cylinder is immersed in water and the volume of displaced water is measured.
- The cylinder is then filled with water and pressurized up to test pressure (This is stamped on the cylinder or it is 5/3 rds of the working pressure).
- The cylinder stretches slightly as this is done.
- Next the pressure is released and the tester again measures the displaced water to determine the cylinders new volume.
- The cylinder will have a small amount of permanent stretch if this is within limits set by the appropriate government the cylinder passes the test.
- Note that if the cylinder fails during the test it will not explode as it is filled with water that cannot expand.

Certain things will require that a cylinder be hydrostatically tested before the normal test period is up; these are:

- If the cylinder has been tumbled or sandblasted to remove corrosion.
- If the cylinder may have suffered any damage due to impact.
- If the cylinder has been exposed to heat in excess of 82 degrees C.
- If the cylinder has been left unused for 2 years or more, especially with zero pressure.

A visual inspection of the scuba cylinder should be carried out at least annually. The exterior and interior of the cylinder is examined to see if a hydrostatic test is required. The valve is removed and serviced and the threads checked for any corrosion due to galvanic action.(More common an aluminum cylinders). The tank valve o ring is renewed and the burst disk in the tank valve is renewed. This is a recommended industry standard but is required by law in the UK every two and a half years.

**Tank Valves:**

- K valve: This is a simple on off valve.
- J valve: This a valve with a reserve mechanism that cuts of the air at around 20-40 bar until the lever is operated. It does not give you more air; only what you already had. Used extensively in diving before the advent of the SPG. When filling a tank with a J valve the lever should be in the down position.
- DIN valve: (Deutsche Industrie-Norm) The regulator screws into the tank valve giving some advantages over the yoke screw design.
    1. It gives a better seal between the tank and the regulator.
    2. The connection is stronger and is preferred by technical. Cave and wreck divers.
    3. It can take up to 300 bar pressure. (Yoke screw max.232 bar).

DIN valves can be J or K valves.

Y valves are tank valves which have two taps and two regulator points, either yoke screw or DIN. This enable two regulator first stages to be attached to a single tank.

Twin tanks have manifold valves, some with an isolator valve in the centre (recommended) so that tanks can used independently in an emergency.

A burst disk is required by law in many countries  and is installed into the tank valve to prevent dangerous over pressurization. This is a thin copper disk that ruptures and allows the air to escape when the pressure reaches 125% to 166% of the working pressure of the cylinder. Burst disks are available with different burst pressures. They stretch over time and should be renewed annually when a visual inspection is carried out.
Another method of achieving this safety feature is a hole on the thread of the tank valve a couple of threads up, if the tank is over pressurized the air then leaks up through the thread and escapes from the top of the tank valve.

All tank valves have a plastic or metal anti debris tube that extends from the bottom of the valve into the cylinder. If the cylinder has some debris from accumulated rust or a small amount of water is present this prevents this from traveling through the tank valve to the regulator.

**Regulators:**

First we will look at the three types of scuba (self contained underwater breathing apparatus) available to the diver and how each one works.

1. Open Circuit Scuba: This is probably the one you are more familiar with and is certainly the most commonly used and will be for the foreseeable future given the inherent simplicity and safety record of the unit. The diver inhales air from a cylinder via a demand valve regulator and exhales it into the water, thus the circuit is open because none of the air is recycled. This system is often referred to as "*open circuit demand*".
2. Semi-closed rebreather (SCR): This has now crept into recreational diving and several courses are available. The diver inhales from a breathing bag that receives a steady flow of gas (usually enriched air nitrox). The diver exhales back into another bag and the gas has carbon dioxide removed chemically. Excess gas from the steady flow trickles out through a valve. The circuit is semi-closed because part of the gas is recycled and part of it is released.
3. Closed circuit rebreather (CCR): This is still in the realm of the technical diver although becoming more popular with the sport diver as time goes on. The diver inhales from a breathing bag and exhales back into another one, the gas has carbon dioxide removed chemically , it is then analyzed by oxygen sensors and a solenoid tops up the bag with oxygen as required. The diver adds dilutant air to the bag as he descends. Air is only released on ascent for buoyancy control. The partial pressure of the oxygen is monitored giving an ideal gas mix for whatever depth the diver may be. This greatly reduces any decompression penalties. Special unit specific training is required.

Let's now look at how an open circuit regulator works…..

The *first stage* reduces *high pressure air from the tank to an intermediate pressure* (usually around 10 bar above ambient).

When the diver inhales the intermediate pressure in the first stage drops below it's normal level.

This allows the water pressure to flex a diaphragm or move a piston that releases air from the tank.

The air flows as long as the diver inhales keeping the first stage from reaching intermediate pressure.

When the diver stops inhaling the pressure rises back to intermediate pressure in the first stage and closes the valve from the tank.

The *second stage* reduces the *intermediate pressure to ambient pressure* for breathing.

When the diver inhales water pressure pushes in a diaphragm which opens the second stage downstream valve releasing air from the first stage.

As long as the diver inhales, air continues to flow.

When the diver stops inhaling the diaphragm returns to its relaxed position and the valve closes.

Exhaled air exits the second stage through one way exhaust valves.

On some second stage models, the diaphragm opens a small *pilot valve*, which creates a pressure imbalance which opens the main downstream valve.
This reduces breathing effort somewhat, but is a more complex design and is costly to service.

On some models there is a cracking resistance control which can be accessed by the diver. This adjusts the effort needed to open the second stage valve to a personal preference.

On many models you will find a venturi switch accessed by the diver. This deflects air to the diaphragm when in the off or minus position. This is to prevent the regulator from free flowing when getting in and out of the water.
When it is set in the on or plus position it deflects air to the mouthpiece to reduce breathing effort. It should always be in this position once underwater.
To test if this is adjusted OK. If you press the purge button out of the water when the lever is in the plus or on position the regulator should continue to free flow after you release the purge button. To stop this switch the lever back to minus or block the mouthpiece with a finger.

To protect the high pressure seat from excessive wear on the first stage of a regulator. When you open the tank valve hold down a purge button or LPI on the BCD momentarily as you open the valve then release when the air starts to flow. This prevents the valve hitting the seat of the first stage with the full force of 200+ bar!

An *upstream* valve opens *against the flow of air* (like pushing a door open against a strong wind).
A *downstream* valve opens *with the air flow* (like pushing open a door with the wind behind you).

If there is a malfunction in the first stage the intermediate pressure will rise and open the *downstream* valve this will cause a continuous free flow of air rather than shutting off the air. It is known as a *failsafe* design.

*Environmental sealing* applies to the regulator first stage. This is because normal air flow causes the temperature to drop as the gas is expanding, *in very cold water* this drop can cause water to freeze the regulator first stage valve in the open position resulting in a free flow of air. To avoid this some regulator first stages have environmental sealing. This seals silicon grease or a light oil around the first stage which is normally open to the water. The oil then transmits the water pressure to the diaphragm or piston so the regulator operates normally.

A newer way of solving this problem is with a dry sealed first stage this solves the problem without the complications associated with an oil filled first stage.
Heat sinks on the second stage connection are another innovation to lessen this problem. Environmental sealing of this sort is also recommended for warmer water diving, to prevent salt corrosion inside the first stage and stop the possibility of sand or debris getting into the first stage.

An *unbalanced* regulator is one in which the tank air pressure *resists or assists* the opening and closing of valves in the first stage.

This is cheaper to make, it becomes harder to breathe when there is less pressure in the tank. They are no longer commonly found.

A *balanced* regulator is one in which the tank air pressure *neither resists nor assists* the opening and closings of valves in the first stage.

Breathing is easy at all tank pressures, better able to supply two divers and better for deeper diving. Nearly all modern regulators are of balanced design.

*A rational on piston and diaphragm regulators: At one time piston regulators were said to be better but more prone to freezing up in cold water. In modern regulators it does not make an iota of difference. Although most high performance regulators designed for deep and technical diving are of a diaphragm design, but not all and the piston versions are just as good.*
*How did all this happen. As you know our old friend Jacques Cousteau invented the regulator and got his friend Emile Gagnan to design one. This was patented as the Aqualung and he had a monopoly exporting from France all over the world. A company then called "Dive Air" in the USA (Now Scubapro) invented the piston regulator to get around the patent. Most modern makes of regulator branched off from one of these original companies and although nearly all make both diaphragm and piston regulators, you will find that most of their range will reflect which of the original parent companies they originally came from.*
*An interesting but true story – they used to test new designs in the sea to 75 meters on air to see if they would work!! I think we all know better than that nowadays.*

We covered dive computer use in the last section on decompression theory now we will take a look at all the other gauges divers carry.

**Depth gauges:**

*Capillary depth gauges* are a simple piece of clear tubing, sealed at one end and open at the other, with depth increments indicated to where the water column rests according Boyle's Law. (Remember the physics in section one). The deeper you go the closer the depth increments become. They are inexpensive and reliable but are difficult to read in over 10 meters. They are used for altitude diving as they will read theoretical depth instead of actual depth as they are based on Boyle's Law, they are OK for snorkelers and for technical divers doing decompression stops as a back up gauge as they are accurate in shallow water.

*Open bourden tube gauges* contain a spiral shaped tube. Water enters the tubes open end and the increasing pressure causes the tube to straighten. This then moves the depth gauge needle. They are prone to clogging as the tube is open.

*Oil-filled bourden tube gauges* use a sealed tube in an oil filled housing, in this case the pressure transmitted by the oil to the tube causes it to tighten and move the depth gauge needle. These are better as they are not prone to clogging.

*Diaphragm depth gauges* function by connecting a flexible diaphragm to a series of levers and gears that move the display needle. These are more accurate than bourdon tubes but more expensive, they used to be the choice of the serious diver before the advent of dive computers.

*Digital depth gauges* are electronic gauges that read depth via a transducer, which varies the electrical current according to the pressure exerted on it. The greater the pressure the more current they produce. They provide a digital display. These offer the highest degree of accuracy and are used in dive computers and dive watches for determining depth.

**Submersible Pressure Gauge (SPG):**

The SPG works on the same principle as the bourdon tube gauge. High pressure air enters a C – shaped tube and causes it to straighten causing the needle to move. These become less accurate over time usually giving a higher reading as the tube weakens. As long as the needle returns to zero you are safe. (And you can pretend you have more air than everyone else!)

Electronic SPG's use a pressure transducer similar to those in dive computers and are very accurate. These may be integrated into the computer which is attached to the high pressure hose or a hoseless radio version with the sender attached to HP port of the first stage and the display on the divers wrist. If you invest in this expensive kit don't be surprised if you seem to always have less air than your mates – their SPG's will be reading high. Try swapping them around and you will see what I mean.

**Compasses:**
The needle of the compass always points to magnetic north because the needle is a magnet. With most dive compasses the diver reads the heading directly against the needle. New electronic compasses give a digital reading, beware because they still have a traditional needle and swivel under the display so you still have to hold them level, you can tilt them a little bit more than a traditional compass but they can still get stuck.
All these compasses are oil filled so the housing withstands the pressure, this also dampens the needle movement for easier reading. Sometimes a bubble forms in the oil nobody has worked out how this happens yet!

**Gauge Carrying options:**

1. Wrist mounted: the diver straps the gauge to the wrist; useful for compact instruments. It is the most accurate placement for compass other than holding it. More streamlined than a console on the chest, especially in overhead environments. Can be more prone to entanglement.
2. Console: Combines several instruments into one package on the SPG or may integrate several instruments into one, such as a pressure integrated dive computer. This speeds up dive preparation, keeps arms clear for putting BCD and tank on and off. The console requires securing so it doesn't drag and damage the environment or itself.
3. Retractable mount: Gauge mount clips to BCD with a spring wound retraction cord. The diver pulls it out to read then it retracts out of the way. Good for hand holding a compass, good for hoseless computers for divers that don't like them on their wrist.

Most divers will use a combination of all three methods depending on the environment and the type of diving they are doing; all have their advantages and disadvantages.

**Enriched Air Equipment Considerations:**

We already started this discussion when we talked about cylinders earlier in this section.
Apart from the Oxygen cleaning and the general identification labels, each nitrox tank must have a visual inspection label stating it is oxygen clean for partial pressure blending or not oxygen clean and only suitable for continuous blending with mixes less than 40% oxygen. The cylinder must also have a contents sticker identifying the current blend, fill date, maximum operating depth and the analyzer/divers name.
*Each diver must personally analyze the gas in his own cylinder before using it.*

*A rational on dust caps and there use and none use etc……*

*When we are learning to dive our instructor should have told us to dry and replace the dust cap on the regulator after use. This not emphasized enough as is born out by the amount of divers who continue to rinse regulators without dust caps in place whether they are rental regulators or the own!*
*Their normal response to this is to connect the regulator back on the tank turn the air on and hold down the purge buttons on the primary second stage and the octopus! Excuse my French but that is one f***ed regulator.*

*Let's look at what happens….*

- *The regulator is dumped into the rinse tank without the dust cap in place.*
- *Water seeps through the filter and into parts of the regulator where only air and not water is supposed to go.*
- *The diver puts the regulator back on tank and turns on the tank valve.*
- *Air pressure forces water deeper into the first stage parts and down the medium pressure hoses to the LPI, primary and octopus.*
- *Air pressure also forces water down the high pressure hose into the SPG.*
- *The diver then purges his primary and octopus in the belief that this will blow all the water through.*
- *The diver gets to use the regulator a few months later, he finds that his SPG looks a bit funny, he can't stop his octopus free flowing and the air tastes funny.*
- *The SPG has a small amount of water in it and will eventually corrode and stop working.*
- *The octopus is free flowing as the back side of the downstream valve has started to corrode, normally no moisture would enter here.*
- *His air tastes funny because there are bacteria growing inside his medium pressure hose.*

*Now doesn't that sound like an incident or few waiting to happen?*
*Perhaps it should be called a water cap instead of dust cap.*
*If this was rental equipment some other poor unsuspecting diver gets the problem.*
*To avoid such problems and save loadsamoney on servicing do the following:*

*DO replace the dust cap as soon as possible after you remove the regulator from the tank valve.*
*DON'T put the regulator down until you have done this.*
*DO blow dry the dust cap with tank air or better with a towel before replacing it.*
*DON'T blow air from the tank at the filter; this pushes water into the first stage.*
*DO rinse you regulator while it is still attached to the tank, if possible, by hose.*
*DON'T leave you regulator soaking even with the dust cap in place water can still seep in. Especially with DIN fittings that should always be rinsed on the tank.*
*DO have the regulator properly serviced ASAP if you accidentally flood it.*
*DON'T use or repressurize the regulator after flooding the first stage.*

## SKILLS & ENVIRONMENT SECTION 5

**CESA:** Controlled emergency swimming ascent; this should done with all equipment in place. The diver should ascend at a rate not to exceed 18m/min and have his right hand above his head, his left hand held up covering the deflate button on the LPI, looking up and making a continuous aaah sound exhaling through the ascent.

**Signals:** You should know the meaning of the 25 PADI standard diving signals.

The signals are as follows:

| **Meaning of signal** | **Description** |
|---|---|
| Stop | Hand held upright, palm out |
| Something is wrong | Hand held out flat horizontally and swiveled from side to side |
| OK, OK? | Tips of index finger and thumb held together, fingers straight. |
| OK, OK? (with gloved hand) | Tips of all fingers and thumb held together forming an “O” |
| Distress, Help | Waving arm up and down |
| OK, OK? (on surface at a distance) | Arms forming an arc above the head tips of finger together |
| OK, OK? (one hand occupied) | Arm forming an arc with tips of fingers on head |
| Danger | Clenched fist held straight out |
| Go up | Thumb pointing up |
| Go down | Thumb pointing down |
| Low on air | Clenched fist punched against chest |
| Out of air | Slashing motion across throat with flat hand |
| Buddy breathe or share air | Cupped hand moved back and forth towards mouth |
| Come here | Arm held out, palm flat then, brought up in a beckoning motion |
| Me, or watch me | Finger pointing at the chest |
| Under, over or around | Arm held out palm down and moved in direction required |
| Level off, this depth | Hand held out palm down and moved from side to side |
| Go that way | Point thumb in direction you want to go |
| Which direction? | Clenched fist with thumb held out and swiveled back and forth |
| Ears not clearing | Finger pointed at ear |
| I am cold | Arms hugging oneself |
| Take it easy, slow down | Arm held out, palm down and moved slowly up and down |
| Hold Hands | Hands clenched together |
| Get with your buddy | Index fingers held together, rest of fingers clenched |
| You lead, I’ll follow | Pointing with index fingers of both hands, one behind the other |

**Buoyancy check:** The diver should enter water too deep to stand up in wearing all equipment. The diver should float at eye level while holding a normal breath and no air in his BCD.

*On PADI questions* the answer is always at eye level regardless of whether it is at the beginning or end of the dive.

Overweighting causes extra drag, puts the diver in the wrong position and should never be done.

**First Aid:**

With an unconscious diver in the water the steps are as follows:

- Establish buoyancy
- Check for breathing
- Call for help
- Give 2 slow breathes
- Protect airway and give one breath every 5 seconds
- Tow to shore or boat while removing equipment (breaths take priority).

You cannot perform CPR in the water therefore you assume pulse with a non breathing diver. As soon as he is on a boat or back to shore you can perform a circulation check and administer CPR if necessary.

When performing CPR the ratio of compressions to breaths is 30:2

The rate of compressions should be 100 per minute.

First aid for DCI has already been discussed in previous questions. One point though, NEVER TRY TO PUT A DIVER BACK IN THE WATER TO RECOMPRESS HIM.

Also if you run out of oxygen you can use any nitrox mix available which is better than air. Obviously, the higher the percentage of oxygen in the nitrox the better it is for the diver.

In the case of a near drowning victim, one who has been resuscitated and recovered, they should always be taken to medical care as secondary drowning can occur later – even if they say that they feel fine.

*Note: Even in questions on DCI the PADI answer is always take the patient to the nearest medical facility, not the nearest recompression chamber. The rationale behind this is that the patient needs medical back up as well as recompression.*

Marine life injuries can cause varying degrees of stinging, itching and pain and sometimes respiratory arrest and cardiac arrest (death).

Protocols are as follows:
With jellyfish and coral stings apply vinegar.
Wash and disinfect any wound that has broken the skin.
With lionfish, scorpion and stonefish stings apply heat to the wound with hot water for at least 30-90 minutes; this will cook the protein in the poison and stop it from spreading.

With other injuries you would follow your primary assessment, and provide the indicated care.

**Environment:**

To protect the aquatic environment the diver should be correctly weighted and maintain good buoyancy control. Look but don't touch. Avoid contact with the bottom. Make sure that no hoses are dangling. Do not feed fish.

**The sea:**

Waves are directly caused by *wind.*
Waves break when the depth of the water is the same as their height.

A *rip current* moves out to sea (*seaward*).
A long shore current moves along the shore.
Sand *ripples* generally run *parallel* to the shore.

Tides are primarily caused by the *moon and the sun.*
When the moon and the sun are in line or opposite each other we have spring tides.
When the moon and the sun are at right angles to each other we have neap tides.
The strongest currents will appear during spring tides.
The *geographical features* and topography of an area dictate the *range and duration of tides* as well as the gravitational pull of the moon and the sun.
The best time to dive is at *high slack water.* This will produce the least current and the best visibility.

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*.

**Search and recovery:**

Never try to lift and object with out a lifting device that weighs more than 4-7 kilograms.

When deciding on a search pattern and method take the following factors into account:

- Current
- Visibility
- Experience of divers
- Underwater topography
- Size of the object.

**Compass navigation:**

To return on a reciprocal heading rotate the bezel 180 degrees.
To complete a triangle rotate the bezel 120 degrees for each leg.
To complete a rectangle rotate the bezel 90 degrees for each leg.
To complete a pentagon rotate the bezel 72.5 degrees for each leg.
To complete a hexagon rotate the bezel 60 degrees for each leg.
To complete an octagon rotate the bezel 45 degrees for each leg.
To complete a dodecahedron rotate the bezel 30 degrees for each leg.

*If you want to complete any other weird shapes work it out for yourself!*

**Equipment:**

An alternate air source should be place in the triangular area between your chin and the lower corners of your rib cage.

A weight belt should have a quick release, requiring the use of only one hand.

A buddy check should be made before every dive:

| | Rec | Tec | Equipment |
|---|---|---|---|
| B - | Begin | Being | BCD |
| W - | With | Wary | Weights |
| R - | Review | Reduces | Releases |
| A - | And | All | Air |
| F - | Friend | Failures | Final OK |

**Enriched air divers should personally verify there cylinder contents before diving**.

*All of the other things that could come up in the skills and environment exam we have covered in the other sections. If you can think of something else let me know.*

Finally let's look at some current diving definitions:

**Recreational Diving:**
Diving for pleasure to a maximum depth of 40m using air or enriched air nitrox and staying within no decompression limits, using open circuit scuba or a semi-closed rebreather and not penetrating caverns, caves, wrecks or other overhead environments further than the light zone or 40m linear distance to the surface.

**Technical Diving:**
Anything more than the definition above; currently PADI Tec Rec certs have the following limitations:

Tec40 : No more than 10 mins decompression using up to 50% oxygen for added conservatism. Maximum depth 40m.
Tec45: Decompression using up to 100% oxygen for added conservatism or accelerated decompression with a single deco tank. Maximum depth 45m.
Tec50 : Making extended range gas switch dives requiring decompression stops to maximum depth of 50m using air and enriched air with up to 100% oxygen.
Tec Trimix 65 : Making extended range gas switch dives requiring decompression stops to a maximum depth of 65m using trimix, air and enriched air with up to 100% oxygen. No less than 16% Oxygen in the Trimix.
Tec Trimix Diver : Making extended range gas switch dives requiring decompression stops to a maximum depth of *90m* *using trimix, air and enriched air with up to 100% oxygen.
* This the DSAT limit for training dives. After completion deeper dives may be made as the diver builds experience.

DSAT will continue to extend its range of technical courses in the future. Distinctive DSAT Specialties can now be submitted. A rebreather working group has been formed as these become more popular. At the time of writing, training with other agencies is possible in the following areas.
CCR   Closed circuit rebreather *unit specific training.*
CCR   Mixed gas *unit specific training.*
Deep wreck penetration. Beyond the light zone and more than 40m linear distance from the surface utilizing the techniques of technical diving. Dive Aqaba now have a distinctive specialty approved for this “Advanced Wreck Diver”
Cave diving using OC technical equipment and rebreathers.