Dive Computers

By Vlad Pambucol
DiveCon candidate
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Introduction

Why SCUBA?
Scuba is a sport and hobby that fascinate allot of people but what does it takes to be able to tell that you really like SCUBA. Well, it takes more that going once a year somewhere where the sun never stops shining and the sunsets paint red colors on the clouds and the water. What all of us, the ones we really like SCUBA have in common? The love of water? The love of adventure? The love to be alone with your dive buddy and the ocean? The love to discover strange new worlds? The love to see what has never been seen before? The love of being and trusting friends with your life?
Probably we have all those things in common and much, much more.

For me the adventure started when I was 7 and once at the Black Sea one of my father friends bought me some snorkeling gear. That's how all started and I never stopped. Each year after this I went to the Black Sea and took my snorkeling gear with me (which by the way I still have and treasure – a black and hard mask and some blue heavy fins). Snorkeling was great and I did it for 20 years but I always wanted to stay more under water. Of course I have seen on TV those guys wearing strange suites and breathing compressed air from SCUBA bottles. Of course I wanted to be like them and of course my dream was to be able to go and explore the depths of the ocean lie Jacques-Yve Cousteau. I couldn't do it for 20 years and it took a short flight over the ocean to the US for me to start SCUBA.

Training was fantastic. Instructors and DiveCons were great.
BUT probably the most fantastic of all was how I felt after 20 years of snorkeling and after being accustomed with about 1-2 minutes underwater, to take a breath of compressed air and being able to stay for 3 minutes and 30 minutes after that and 30 minutes after that…
Along the years I got more certifications and more dives and I got more experience and I will continue to take more lessons and when the times comes I will take my turn in the he teaching team to introduce to some other enthusiast the wonderful underwater world.

In my day job I am a firmware engineer so another fascination of mine (which started by the way when I was 7 also) is computers and programmable devices. Of course the dive computers caught my attention as soon as our diving instructor told us about them in the class.

I will try in this presentation to tell you all you always wanted to know about computers but you were afraid to ask and much, much more.

A little bit of gas theory

This chapter explains why we can't stay underwater for a long time even with an unlimited supply of air and why we should surface slow and follow the SSI diving tables to plan and do dives.

Diving Physics

Water is denser and heavier than air because in an equal space, water contains more molecules than air. A cubic foot of salt water weights 64 pounds (a cubic foot of fresh water weights 62.4 pounds) and a cubic foot of air weights 0.0881 pounds. We know that a square inch the height of the entire atmosphere exerts the same pressure as a one-inch square column of water 33 feet deep into the ocean. Therefore a diver under water will feel the pressure of the atmosphere and the pressure of the water above his body.

Water is much better heat conductor than air so a diver under water will loose more heat than in air. Air temperatures of 80º F will feel comfortable but under water it will seem cold. Water absorbs body heat 25 times faster than air. This "pulling away" of heat is due to the property of heat energy transmission known as *conduction*. Conduction can be slowed or stopped by placing a pour heat conductor between the body and the water.
Convection and radiation are the other two methods of heat energy transmission but they have little or no effect on the divers.

The pressure felt by a diver (absolute pressure) is the sum of the hydrostatic pressure (the pressure of the water which results from the weight of the water) and the atmospheric pressure. If you are under water at a depth of 33 ft. the hydrostatic pressure is 1 ATM, the atmospheric pressure is 1 ATM so the absolute pressure is 2 ATM. A depth gage will only measure the hydrostatic pressure so at 33 ft. the depth gage will measure 1ATM.
Here is a chart that shows the comparison between the pressure in bars, ATM and psi.

ATM	PSI	BAR	DEPTH
1	14.7	1	Sea level
2	29.4	2	33 ft (10m)
3	44.1	3	66 ft (20m)
4	58.8	4	99 ft (30m)
5	73.5	5	132 ft (40m)

If a gas if formed from a mixture of gases, the partial pressure of one of the component gases is defined as the pressure of that gas in the mixture.

Gas Laws

Dalton's law

John Dalton, an English chemist and physicist, lived from 1776 to 1884. In addition to discovering a law of physics, he also made the first scientific account of color blindness, mostly because he was afflicted with it. He formulated his law of partial pressure while trying to solve a problem with Newtonian physics. His law states:

> *"The total pressure exerted by a mixture of gases is the sum of the pressure that would be exerted by each of the gases if it alone where present and occupied the total volume."*

For example at the sea level the atmospheric pressure is 14.7 psi. Air, which is a mixture of gases, consist of 78.08% nitrogen and 20.95% oxygen, 0.03% carbon dioxide and 0.94% other gases.
The partial pressure of the nitrogen at the sea level is

$$0.7808 * 14.7 = 11.48 \text{ psi}$$

The partial pressure of the oxygen at the sea level is:

$$0.2095 * 14.7 = 3.08 \text{ psi}$$

For divers this means that at any depth or pressure the proportion of the nitrogen and oxygen in air will remain constant. However, when the pressure increases the partial pressure increases in proportion to the change in pressure.

Boyle's law

Robert Boyle was an English scientist who lived from 1627 to 1691 and was a friend and contemporary to Isaac Newton. He developed his law of pressure to show that air consisted of particles that behaved like tiny, coiled springs. In 1662 he published his finding that states:

> *"For any gas at a constant temperature, the volume will vary inversely with the absolute pressure while the density will vary directly with the absolute pressure."*

This means that if pressure increases volume decreases and if pressure decreases volume increases. The change in volume is predictable and can be calculated. For example an 80 cubic feet *flexible* container (at 1 ATM) will decrease to 40 cubic feet at 2 ATM.

For divers, this is the explanation for the need of equalization on descend and on ascent and for the other pressure-related occurrences such as squeezes. It also explain why air is consumed faster at depth and the danger of the air expansion injuries.

Charles' law

Jacques Charles was a French scientist who showed the how the temperature influence the volume of a gas under pressure. His discovery elaborated on Boyle's work that assumed a constant temperature. His law states:

> *"For any gas at a constant pressure, the volume of the gas will vary directly with the absolute temperature. For any gas at a constant volume, the pressure of the gas will vary directly with the absolute temperature."*

When air is cooled molecules come closer together, which makes the air denser. Dense air takes up less space so its volume decreases. If the air is inside of a balloon, heating the air would make the air to expand causing the balloon to increase in size.

For divers Charles' law has implication in the SCUBA tank filling process. If a tank is filled at an ambient temperature of 70º F and after that the ambient temperature rise to 80º F the pressure inside the tank increases since the volume of the tank is constant.

Henry's law

William Henry, an English chemist and physician, lived from 1774 to 1836 and conducted concurrent investigations into the solubility of the gases with John Dalton, who was researching the partial pressure of gases. In 1802 he developed Henry's law, which states:

> *"The amount of any given gas that will dissolve in a liquid at a given temperature is a function of the partial pressure of the gas in contact with the liquid and the solubility coefficient of the gas in the particular liquid."*

According to Henry's law, pressure will force a gas into solution. Conversely, if the pressure is removed, the gas will come out of solution and return to its original form.
The classic example of Henry's law is the soda bottle.

For divers the concept of a gas coming out of solution has major implications. During a dive, nitrogen is absorbed into the diver's tissues. On ascent, pressure decreases and the nitrogen will come out of the solution as bubbles if the pressure is decreased to quickly. If this occurs while the nitrogen is still in the diver's tissues, decompression sickness

(DCS) results. The rat with which the nitrogen is coming out of the solution can be controlled by slow ascents (30 ft. per minute).

More about bubbles. Bubbleology 101[1]

You know that bubbles are trouble, and that they come from nitrogen. But if you're like most divers, decompression theory—the nuts and bolts of bubble making—is an intimidating mystery. Just what does "supersaturation" mean? What the heck is a "tissue compartment" anyway?

Tired of scuba bullies kicking verbal sand in your face? For that matter, are you tired of your dive computer—that other bully—giving you preemptive orders for no apparent reason? Or maybe you'd just feel better knowing what's really going on inside your body. As it happens, decompression theory is not as confusing as you might think. In fact, you just need to have ridden a subway once in your life. Or seen a subway in a movie. Or heard it described. It's that easy—trust me.

How Nitrogen Dissolves in Your Tissues

You know already that nitrogen enters your body with the air you breathe and passes through your lungs into your bloodstream, where it is carried all over your body and deposited in your tissues.

Gas molecules are not attracted to one another. In fact, they try to push each other apart—the pushing is called gas pressure. So, in escaping one another, molecules of nitrogen disperse among your blood cells, pass through the walls of your blood vessels and, in a sense, head for the lonely, empty spaces inside your various tissues. When the nitrogen molecules are dispersed and mixed with the other molecules of your body like this, the nitrogen is called dissolved and is harmless. Only when the nitrogen molecules (and other gas molecules) are forced to associate do they form those troublesome groupings called bubbles. Imagine a grouping of securities traders entering a subway car. Together, they are competitive and obnoxious—yelling "Debenture!" and "Yo Mama!" at one another. But if there are empty seats, they will quickly lunge for them ("Lookout, lady!") and disappear into their laptops.

What Is Saturation?

When nitrogen or other gas molecules have filled all the available spaces in your tissues, the tissues are called saturated. (The subway car is filled when all the seats are occupied and all the standing room is taken.)

Why Saturation Depends on Depth and Dive Time

More depth means the nitrogen (and other breathing gas) comes into your body under more pressure. More pressure means, essentially, more molecules of nitrogen crowding into the available space. They try, however, to go to where there is less crowding—less

[1] By John Francis. A New Diver's Guide to Understanding and Avoiding DCS. http://www.scubadiving.com/training/instruction/bubbleology101/

pressure. They will continue pushing into your tissues until the mutual antagonism between them—the gas pressure—in the tissues equals the pressure of the breathing gas coming in. At that point, crowding is the same everywhere, nitrogen molecules have no incentive to move and you stop absorbing more of them.

How many people can crowd into a subway car? Depends on how many want to get on—and on how hard they push.
But this doesn't happen instantly. It takes time as well as pressure to reach saturation. How many people can crowd into a subway car also depends on how long the doors stay open.

What Happens When You Go Deeper
After enough time at, say, 60 feet, your tissues will become saturated for that depth and no more gas will enter them. But if you then descend to 90 feet, the increased pressure will drive in more gas until a new level of saturation is reached.

You thought the subway car was full until you reached a station with a big crowd wanting to board. The seat next to the smelly psychotic suddenly looks attractive. Strap-hangers double up. Somehow, there's always room for a few more passengers.

What Happens When You Ascend
If you return from 90 feet to 60 feet, the pressure of incoming breathing gas is less than the pressure in your tissues, which are now called "supersaturated" (a six-bit word for "overcrowded" or "overpressured"). Nitrogen now wants to leave those tissues, via your bloodstream and lungs, and join the lower-pressure (less crowded) gas you exhale. Of course, leaving causes the pressure in your tissues to drop. Nitrogen will continue to leave your tissues until the pressures again equalize and a new level of saturation is reached.

Tissues Are Not Created Equal
Clear so far? It would be if all the parts of your body absorbed and released gas at the same rate. But they don't. Some take longer to reach saturation than others.

It has been known (or, at least, theorized) for a long time that thousands of different organs and parts of organs in your body reach their fill of nitrogen at thousands of different rates—ranging between instantaneous and glacial. Imagine that some subway cars have more doors and bigger doors than others—that, in fact, each car is different.

The theory's not proven, but scientists like it because it explains why longer bottom times usually cause more bubbles and bubbles in different places: more areas of tissue have had time to reach their limits of dissolved gas.

It also explains why some tissues can be overfilled and release gas while others are still absorbing it. For example, you go to the bottom and stay there until a "fast" tissue completely saturates. A neighboring "slow" tissue, however, is still just beginning to fill.

If you now ascend only a short distance, the reduced pressure lets gas escape from the saturated tissue, while the mostly empty tissue can go on filling.

Tissues May Affect One Another

More theory: It seems reasonable to suppose that if a full tissue is next to a nearly empty tissue, nitrogen might pass directly from the full to the empty tissue. If the subway cars have connecting doors, some of the people in the full car will pass through to the empty one. At any rate, that would explain why slow tissues can continue to take on nitrogen even during your surface interval: They are absorbing it directly from faster, already-filled tissues nearby.

Why Bubbles Form

Remember that when you ascend after reaching saturation, the pressure keeping nitrogen dissolved in your tissues drops and the nitrogen wants to get out of your body. Basically, if the pressure drops faster than your body can process the exiting nitrogen, it clumps into bubbles. If too many passengers want to leave the subway car at one stop, they crowd together and can't fit through the doorway in time. When enough of them miss their stops, they'll become a mob and wedge the doors or smash the windows to get out.

Why Bubbles Don't Form When They Should

Bubbles don't form easily. For one thing, tissues seem to be able to tolerate a certain amount of overfilling (supersaturation) before bubbles form. That's called the tissue's M value (M for maximum). And once again, tissues differ wildly from one another. In general, fast tissues seem to have higher M values—they tolerate more overfilling of dissolved nitrogen before bubbles form than do slow tissues.

That's why you can have a bottom time of 30 minutes at 90 feet by the U.S. Navy tables, yet ascend to the surface without making a deco stop. Your fastest tissues became full (saturated) in 30 minutes at 90 feet, but thanks to the tissue's tolerance for supersaturation, a controlled ascent rate gives enough decompression. But longer bottom times will fill less forgiving tissues, making deco stops necessary.

What About "Silent Bubbles"?

It seems that gas molecules are more likely to clump around a nucleus of other gas molecules—a microbubble or a "silent" bubble. Apparently, nitrogen can remain dissolved despite being supersaturated, until some of these microbubbles arrive on the scene. The nitrogen molecules then join the microbubbles, which grow into real, DCS-sized bubbles.

Think of it this way: Those disgruntled, trapped subway passengers probably won't do anything until the alpha male among the securities traders says, "We gotta break a window." Then they become a mob.

We say "apparently" because this is another theory, first proposed by A. R. Behnke in 1942. He called them "silent" bubbles because they seemed to pass through your system without causing DCS symptoms.

The microbubbles themselves seem to be real enough. Modern Doppler ultrasound sensing allows us to "see" (actually, hear) them in veins, where blood is returning from tissues to the lungs. And, unfortunately, they are very common. They may be present on most dives, but as long as they are on the venous side of your circulation, they will probably be filtered out by your lungs and do no harm.

Why Do Bubbles Cause Pain, Paralysis and Even Death?
Again, no one knows for sure, but here are the theories.

Bubbles may do mechanical damage. Bubbles tend to grow by attracting nitrogen from solution and by clumping together. They can press on nerves and tear tiny blood vessels. Inside blood vessels, bubbles slow down the flow of blood, which hurts the tissues dependent on that blood supply. (A guy crowds into the subway car with a self-inflatable life raft, which, by some accident ...)
Bubbles may do chemical damage. The nitrogen in the bubble is chemically inert, but the bubble itself may be seen by your body as a foreign invader. If that happens, white blood cells attack it and clotting cells stick to it, making it an even bigger obstruction to blood flow. Meanwhile, alarm bells activate all sorts of other chemicals in the immune system, all of which have side effects. (The crowd jostles the fire alarm, the subway train screeches to a halt, firefighters break in with axes ...)

So, What Do We Know?
That bubbles are bad. Otherwise, not much for sure. Most of what is "known" about decompression is really theory. The actual mechanisms by which bubbles form, move about and cause harm are unproven.

Some animal experiments have been done, but animals are not human divers. Human studies are limited because of expense and the obvious danger to the subjects. Most of them have been done on military divers, who probably don't represent the general diving population in fitness, skill and dive profile.

And divers differ considerably in their innate susceptibility to DCS. Some don't get bent when they "should," others do get bent when they "shouldn't."

The Bottom Line: Practical Advice
Ascend slowly (especially during the last 60 feet) and don't miss stops. A slow, steady ascent is like a slow, steady discharge of passengers from the subway car—no anger, everyone stays calm. For the same reason, don't cut short surface intervals. Don't dive tables and computers to the limit. Because they give you specific numbers, they create a false sense of exactitude. It's not really a line between green and yellow, it's a zone. Factor in what the tables and computers don't know: your age, fitness, hydration level and how warm and rested you are.

DCS Basics: Silent Bubbles And Sawtooth Profiles

A sawtooth profile (with several large ascents and descents) is more likely to result in DCS than a single descent to the same maximum depth for the same total bottom time followed by a single ascent. Why? One theory blames "silent" bubbles, also called microbubbles and seed bubbles. On the first ascent, nitrogen comes out of circulation as microbubbles and travels through veins to the lungs. They are trapped in the alveoli and begin to be breathed out. But if you descend again, pressure redissolves the nitrogen you haven't yet breathed out. It escapes the "bubble trap" of your lungs and resumes circulating with your blood, but now on the arterial side where it moves out to your muscles, joints and spinal cord—the sites where DCS occurs.

DCS Basics: How Compartments Might Connect

Researchers have proposed several models to explain how gas might move between those mythical compartments, and between the compartments and your bloodstream. Each results in a unique algorithm or set of tables.

- Haldane - A "parallel" model: Each compartment fills and empties independently and directly from the bloodstream (each subway car is separate from the others). U.S. Navy tables are based on this model.

- Series - There's the "series" model where all compartments are imagined to be connected in a row and gas enters only at one end (a subway train with doors in only one car, but the cars are connected with doors of various sizes). Canada's DCIEM tables are based on this model.

- EL. The initials stand for Exponential—Linear which assumes parallel tissues that ongas at an exponential (declining) rate, but offgas at a linear (constant) and fairly slow rate. And, though it may be a coincidence, a full subway car doesn't discharge as quickly as it fills because exiting passengers have to disentangle from the others and fight through the crowd. Entering passengers just have to push inside the doorway.

- Slab. This model assumes just one tissue that's exposed to nitrogen on only one side (like one long subway car with a door at only one end). The British Sub-Aqua Club tables are based on this model. Reality is probably a mix, like a train where most, but not all cars are connected and most, but not all have their own doors of various sizes and where rates of entering and leaving cars depend on lots of factors. But you might need a supercomputer to calculate tables on that model.

DCS Basics: What About Tissue Compartments?

They're a more dignified name for those hypothetical subway cars. They don't exist either, but they help explain a theory.

John Haldane invented the idea of tissue compartments, along with the first decompression tables, in 1908. Haldane said, in effect, "We don't know anything. So let's imagine that there are five kinds of tissue. Let's give each one a different time to become filled, crank 'em through our theory, make tables, and see if divers get bent." It was messy, but that's science, folks.

The new tables worked, so the idea of tissue compartments was here to stay. It's only a metaphor, and the number of compartments is arbitrary. But it's no more illogical than a teacher dividing 100 students into five groups (A, B, C, D, F), two groups (Pass, Fail) or 10 groups (90-100, 80-89, 70-79, etc.). It's a simplification you can work with, which gives results you can use in planning.

The fill rates Haldane assigned to his compartments were just as arbitrary. He gave compartments "half times" of 5, 10, 20, 40 and 75 minutes on the theory that the absorption rate of a compartment slows as it fills at an exponential rate.

Here comes just a little math. An "exponential" rate means the five-minute compartment fills halfway in five minutes. The half that's still empty fills halfway in the second five minutes, for a total of 3/4 full after 10 minutes. Half of the remaining quarter fills in the third five minutes, for a total of 7/8 full after 15 minutes. And so on, ad infinitum, though six half-times is considered close enough to completely full—98.44 percent full, to be exact.

Meanwhile, the 10-minute compartment is taking 10 minutes to fill halfway, 20 minutes to reach 3/4 full, and so on. When the five-minute compartment is fully saturated in 30 minutes, the 40-minute compartment is less than half full and the 75-minute compartment is just getting started.

Haldane's idea of half-times, and most of the specific half-times he suggested, are still with us. Recent modelers (and computers to do the math) have given us more compartments with odd-looking half-times, like the Bühlmann ZHL-12 algorithm with half-times of 4, 7.94, 12.2, 18.5, 26.5 and so on up to 635 minutes.

True or False? Test Your DCS Knowledge

T or F: If you're ascending, you're offgassing.
False. On the deeper parts of most ascents, you will be offgassing from some tissues but still absorbing gas in other tissues. Some tissues absorb and release gas quickly (blood, nerves) and others absorb and release slowly (joints, bone). The slow tissues can still be absorbing gas during most of your ascent.

T or F: A slower ascent rate always means less risk of DCS.
False. Many divers are told, "Ascend at 30 feet per minute. Period." But if you've been deep for a short time, you will still be taking on more nitrogen than you lose for the first part of your ascent. Therefore, you might be better off ascending faster for the first part of the ascent, say at 60 feet per minute to 60 feet, then slowing down to 30 feet per minute. It all depends on how deep you've gone and how long you've been there.

This is one reason why some computers now prescribe variable ascent rates. It's also why most decompression stops are shallow, not deep.

T or F: When you return to the surface, you will be offgassing from all tissues.
False. "Slow" tissues can be still absorbing gas directly from nearby "fast" tissues that have become more filled.

T or F: Decompression stops are not part of recreational diving.
False. In fact, it is recommended that divers make two decompression stops on every recreational dive. One is the so-called "safety stop," a minimum of three to five minutes at about 15 feet. Some of the more candid instructors are now calling it a "precautionary decompression stop."
Consider this: When the traditional decompression tables, which do not prescribe a "safety stop" as such, call for one decompression stop it's at 10 feet (U.S. Navy, DCIEM, French Navy) or 20 feet (British Sub-Aqua Club), for several minutes or more, depending on bottom times. Hmmm. Wonder where the idea for the "safety stop"came from?
Some dive computers even calculate the duration of a variable safety stop like a decompression stop, extending it for "violations" like a too-rapid ascent.
And a mandatory slow ascent rate is, in effect, a "rolling" decompression stop, both in its intended purpose (to permit decompression) and in the sense that it prohibits a free ascent to the surface without increased risk of DCS. Recreational diving is often defined as that which allows an immediate ascent to the surface at any time without risk, but in fact there is no such dive.

T, F or Depends: Diving by computer is safer than diving by tables.
Depends. Which computer, and which table? They differ considerably. Even assuming the same algorithm for both, tables offer a safety factor when you round up the depths and times. Computers give you more bottom time—and more risk. They encourage you to dive right to the limit of the algorithm, but the limit is not a line, it's a gray zone.
What can be said for dive computers is that they don't make math mistakes. You're less likely to miss a decompression stop through miscalculation.

T or F: If a table or computer is based on more tissue compartments, it is safer.
False. A lot more important than the number of compartments is what the algorithm does with them—how each is weighted, for example. As an example, the British Sub-Aqua Club tables are based on the "slab" model which assumes just one compartment, yet they are not obviously less safe than others.
Then, too, many of the slow-tissue compartments are not very relevant for recreational diving. For example, a 635-minute compartment will saturate only after two-and-a-half days of bottom time. (Slower compartments do become more important after many days of deep, repetitive diving.)

T or F: Bubbles occur in your body only when the outside pressure on it decreases.
False. In fact, bubbles happen naturally and frequently, regardless of ambient pressure changes. If you can "crack" your knuckles, you are actually popping bubbles in your joints. Bubbles are most likely wherever two solid surfaces separated by liquid (like

blood and other bodily fluids) are moved apart or rubbed together. Turbulence results in the liquid, which causes local spots of low pressure. That's where bubbles form. The process is called tribonucleation. And that's why those natural bubbles happen so often in joints.

T or F: You offgas at the same rate as you ongas.
False. Haldane thought so, but recent research has shown that offgassing is much slower. One reason is that bubbles tend to impede offgassing. They slow down blood flow, and they "capture" nitrogen, which must redissolve out of the bubble before it can pass through the lungs.

T or F: Your dive computer measures your nitrogen loading.
False. That should be an easy one, though it is surprising how many divers think their computer is actually keeping track of their personal body. In fact, the computer is only reporting what a hypothetical human—whose age, hydration and fitness level are different from yours—might be experiencing. It's making a "guesstimate."

History of dive computers

Until the early 1980s almost all the recreational diving was taught by the standards of U.S. Navy tables. Because the Navy tables are not based on multi-level diving profiles, scientists developed algorithms that take into account changes in nitrogen uptake with continuous changes in depth. These algorithms were mainly theoretical models until the microchip revolution made them accessible and workable in a hand-held computer. When the algorithm is programmed into a computer that also senses depth (a simple depth gauge) and measures time, you have a "dive computer."

Automated decompression monitors were discussed for years before they became reality. The first serious attempt at making a decompression meter was in the mid-fifties by the US Navy. The mechanical device tested was not accurate enough to replace the tables and was abandoned. The first mechanical decompression meter available to the public came out of Italy in 1959. Through the sixties and seventies many companies and military departments worked on various designs with little success. The technology they needed to make their design work would not become widely available until the eighties. In the early eighties the microchip technology became more affordable for many applications. At last the number crunching power necessary for computing decompression in real time was available.

The first commercially available dive computer was the Orca Edge developed by Karl Huggins and Craig Barshinger in 1983. This computer was a multi level computer that used the Haldanian model based on the silent bubble work by Merill Spencer.
Since then dive computers have become smaller and more versatile. They are now manufactured by many companies, and incorporate one of several algorithms for calculating nitrogen uptake and elimination.

Haldane's decompression theory.

The first scientific approach to adequate decompression was taken by J.S Haldane in the early 1900. Haldane and his colleagues. Working for the British Admiralty, published their theory in 1908. Haldane's work cantered on the use of half-time theory to describe how tissues accumulate and released nitrogen during diving. Haldane put forward the concept that tissues could be described by time factors, these factors ranging from "fast tissues" to "slow tissues", which controlled the rate at which different tissues took on gases and released them. Tissue half-lives is a method used to describe the time necessary to allow the amount of gas in a particular tissue to change by 50%. Haldane chose 5, 10, 20, 40 and 75 minutes as tissue times based on what was considerate at the time to be the outer limits of diving capabilities. In Haldane's time, bottom time and maximum depths were severely limited by not only decompression, but by the limits of technology. Haldane's theory was based on the following postulates:

1) Tissues absorb and secrete nitrogen at an exponential rate, based on the pressure difference between ambient pressure and the pressure of nitrogen in the tissue
2) Tissues in the human body form a continuous spectrum with various rates of absorption and secretion
3) This continuous spectrum can be modeled by selecting a finite number of tissues

Haldane's method had an immediate impact on diving and tunnel workers, as the rate of injury and death was reduced be half. Even so, the limits of Haldane's theory were soon apparent. Haldane himself recognized the need to continue improve his theory as the concept of half-life to describe the amount of nitrogen tolerated by a tissue during decompression was increasingly inaccurate at deeper depths and longer bottom times. Over the years many researchers, both British and American, have worked on expanding and improving Haldane's work. His theory, much reworked by various researchers since 1908, is known as the Neo-Haldanian and is still the basis for modern recreational diving decompression schedules.

Buhlmann's decompression theory

Haldane considered the tissues as "parallel" tissues so there was no influence in between the tissues. Only the gas dissolved in the blood was affecting those tissues but they were not affecting each other.
Others developed Haldane's ideas over the years. In the mid-1960's US Navy Medical Corps Captain Robert Workman refined the idea of allowable overpressure in tissues, discounting oxygen and considering only inert gasses in the breathing mix, such as nitrogen and helium. Workman's maximum allowable overpressure values (what he called "M-values") were more complex than Haldane's, varying with depth and with tissue type. At around the same time Professor Albert Buhlmann was working on similar research at the University Hospital in Zurich. Buhlmann's research spanned over 30 years and was published as a book, Dekompression - Dekompressionskrankheit in 1983. This book, published in English in 1984, made fairly comprehensive instructions on how to calculate decompression available to a wide audience for the first time and therefore Buhlmann's work became the basis for many dive tables, computers and desktop decompression programs. Three other editions were published, the last in 1995, on which

this document is based. See "An explanation Professor A A Buhlmann's ZH-L16 Algorithm by Paul Chapman" in the annexes.

Dive computers explained

We have seen until now that dive computers are electronically devices that have the smarts to compute underwater your theoretical nitrogen absorption based on different algorithms.
BUT … what is in one of those devices?

Component parts of a dive computer

The case

The computer case is the part that protects the electronics from the water. It has to be rugged and transparent on one side to be able to see the display.
Since a picture is worth a thousand words here is how the case of a computer looks.

Of course this is only one of the designs possible. This design is usually called the "capsule" design.

The main parts of the case are (see picture):

From left to right and top to bottom:

- Back panel which holds the pressure sensor and closes the case
- Indicator rim that explains the different indications from the display
- Back panel closing rim which holds the back panel in place and it screws in the body of the case
- Front cover that serves also as the body of the case. This piece contains all the electronics and the inside parts of the computer.
- PCB[2] holder that holds the electronics of the computer.

The pressure sensor

[2] PCB = Printed Circuit Board

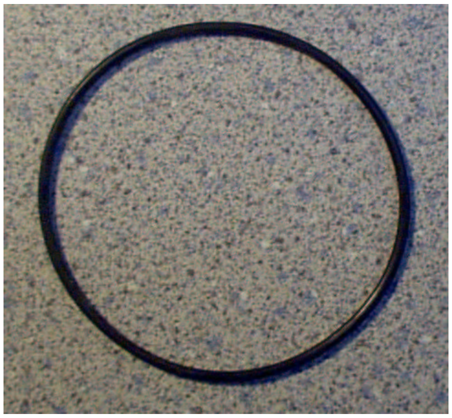
The pressure sensor is the part of the computer that transforms the ambient pressure (hydrostatic pressure) to signals that can be interpreted by the "brains" of the computer. They are usually analog or digital and they don't require calibration.

The analog sensors transform the hydrostatic pressure in a voltage level, of course the voltage level being directly proportional with the ambient pressure. Just as an example let's say that a sensor is calibrated for a pressure of 0 to 10 ATM (hydrostatic pressure) and the voltage that it can generate is 5 Volts. At 10 ATM the sensor will generate 5 Volts so for each ATM the sensor will generate: 5V / 10 ATM = 0.5 Volts/ATM. So, if the voltage the sensor generates is 3 Volts, we can say that we are at a pressure of 3V * 0.5V/ATM = 1.5 ATM.
Since the "brain" of the computer (by the way called microcontroller or microprocessor or in one word CPU[3]) can only process digital signals so only "1" or "0", the voltage generated by the sensor has to be transformed to digital signals. This is done with a chip called an Analog to Digital Converter (or short ADC).

The digital pressure sensor works exactly like the analog one but it has incorporated an ADC inside and it gives directly a digital reading that can be interpreted by the CPU.

The O-rings

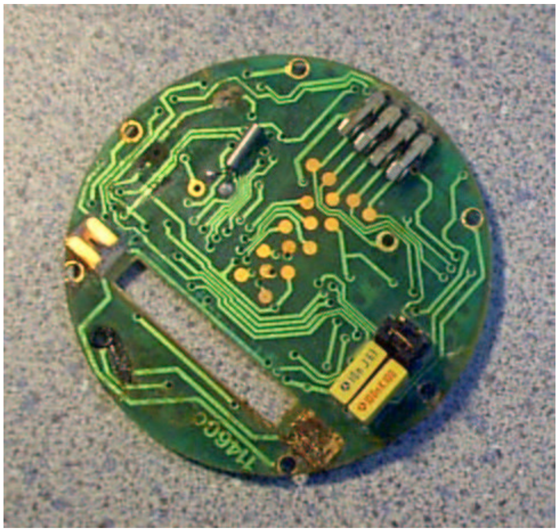
Of course what would be an underwater instrument without O-rings… Well, not much, probably a useless case that will fill with water as soon as the pressure would get bigger. The O-rings are used to make a perfect seal between moving parts of the computer case. Here is how the biggest O-ring on the computer pictured above looks.



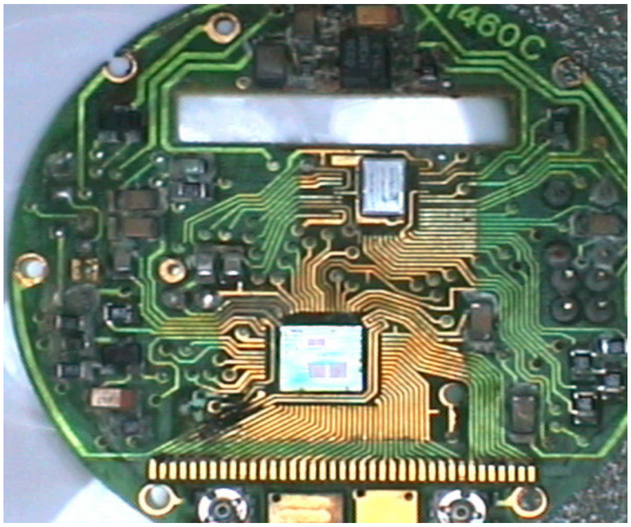
[3] CPU = Central Processing Unit

The electronics on the computer

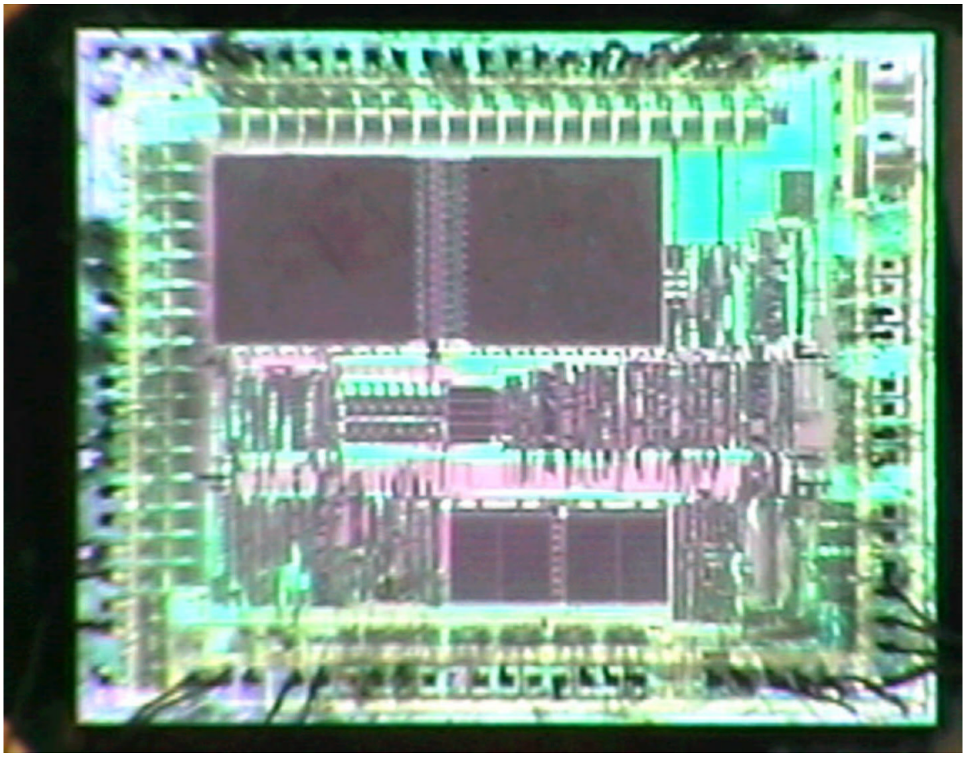
The most important part, or at least the smartest part of the computer is the PCB that contains all the integrated circuits necessary for the operation of the computer.
Here are some pictures of the PCB and some close-ups of the integrated circuits from the PCB.



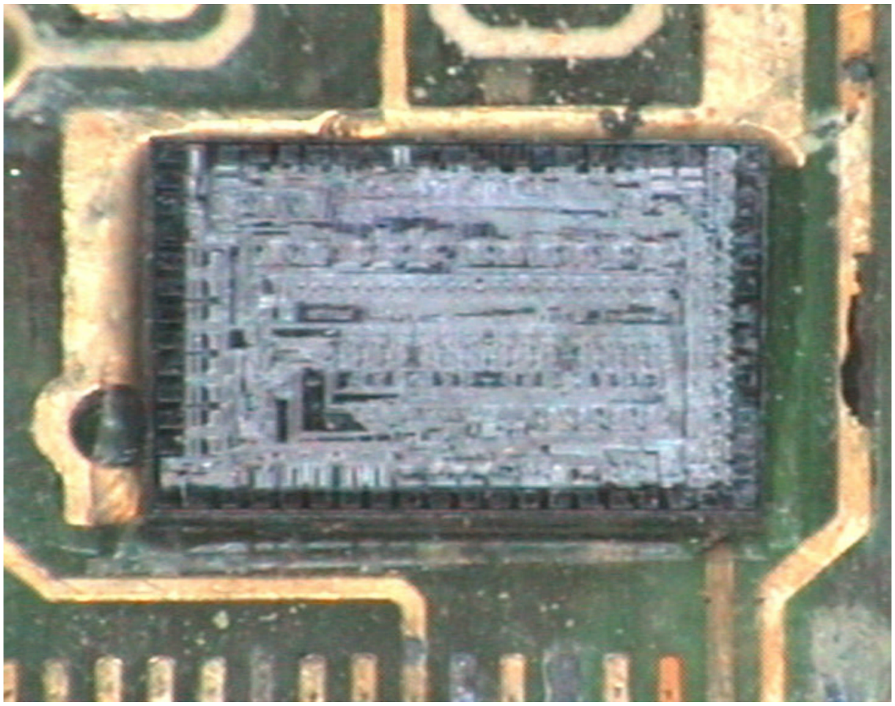
General view of the PCB – side with contacts



General view of the PCB – side with components

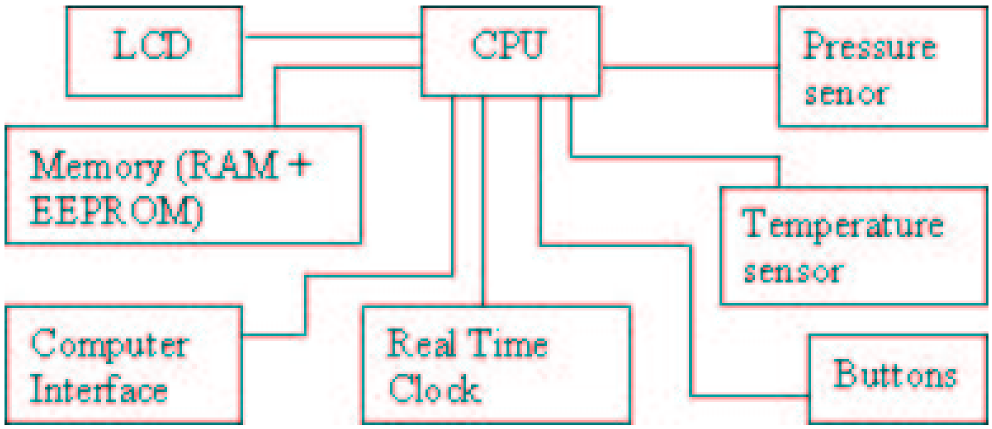


Inside view of the CPU – this is an enlargement of the big shiny “bug” from the “General view of the PCB – component side” photo



Inside view of the memory – this is an enlargement of the small shiny “bug” from the “General view of the PCB – component side” photo

As any "smart device"[4] the dive computers' electronics should have the following parts:



The LCD
This is the Liquid Cristals Display, the part where all the information computed by the computer are displayed. This display is connected to the CPU (usually through an LCD controller) and all the messages the CPU wants to give to the user will be displayed on it.

The CPU
The CPU is the main part and it is the brain of the computer. There are many types of CPUs with different speds and different sizes (I am talking about the operation word sizes – 4 bits, 8 bits, 16 bits and 32 bits -) but all have the same role: execute, instruction by instruction, a program from a memory.
A program (for a dive computer) could looke like this:

- Read pressure
- Compute the nytrogen level based on the time and the current pressure
- Display yhe results on the LCD

The memory
Here are the data and the program saved. Each time you are activating the dive log on your computer you are reading some information stored by the computer in the memory. There are many types of memory but mainly there is ROM[5] and RAM[6]
The ROM is used to store the program which is executed by the CPU and it is written at the factory and the RAM is used for the proper operation of the CPU (for temporary variables) and to store data for your dive profile.

The pressure sensor
See "The pressure sensor" sub chapter above

[4] Smart Device = I am defining a smart device as a device which has a CPU and executes a software program (actually firmware to be more precise)
[5] ROM = Read Only Memory
[6] RAM = Random Access Memory

The temperature sensor

As the name is indicating it, the temperature sensor measures the temperature and it transforms it to a voltage. It can also be analogue or digital and has the same function as the pressure sensor but it offers temperature not pressure. Some decompression algorythms requires the current temperature and it is also nice to be able to record the temperature for your dive log.

The real time clock

What the heck is a real time clock?
Well, it is the hart beat of the computer. Each CPU needs for operation a hart beat which drives the speed of the CPU operations (in modern terms that would be the 800 MHz or 1.2 GHz for a computer you would buy).

The Buton(s)

Usualy you want to interact with a computer and since we didn't got that good to have computers which read our minds or at least that can understand what we talk, we need to communicate what we want them to do by a morse-like language. Lets just say as an example, that one push on the button it puts the computer in Dive Log mode or two short pushes puts the computer in Dive Plan mode. The buttons can be multiple buttons and they can have different shapes and sizes. They can be mechanical contacts or weat contacts.

The compute interface

This is the interface through which the dive computer communicate with a personal computer. Since we got really geeky and we also want to record the dive information for pure pleasure or for later study, the new dive computers incorporte an interface through which we can download diving data from the dive computer to a PC. The PC after that can display all the dive information including usually dive profile and dive log information. For more explanation see the chapter about "Computer interfaces, protocols and trends"

Optional components

What else can we find in a dive computer. … Probably anything we can think off from microwave ovens to washing machines… As long as somebody would request a feature somebody will put it in a dive computer.
Just to be more realistic some other usual components can be: buzzer or speaker for allarms or messages (yes, somebody designed a computer which is reading to you the current dive information), small light to illuminate the LCD, radio receiver to receive the air pressure information for the air integrated computers, etc.

Dive computer classification

It is really hard to do a clasiffication of dive computers. What would be the criteria to clasifficate them? Air integration? Decompression algorythm? Component parts? PC downloadable?
Any of those clasiffications would be ok so I am going to choose one of them.

Air integrated computers

These computers measure tank pressure and must be attached directly to a high pressure hose connected to the regulator. Therefore these computers often completely replace the analog gauge console. These monitor the rate at which air is consumed. These computers then estimate how much breathing time a diver has. The computer then will tell the diver how much dive time remains using the more conservative time of breathing time left or no-decompression time left. This can enhance safety in that while a certain dive profile may say that there is lots of dive time left, air time may be the limit to the divers bottom time.
Some air-integrated computers are hoseless in that a pressure sensor with a data transmitter is hooked directly into the high pressure port of the regulator. Tank pressure measurements are then transmitted directly to the wrist mounted computer. Thus the computer can still display tank pressure and air time remaining without being connected directly to a high pressure hose. These units are very useful when it comes to attaching redundant gauges to a regulator. Normally two pressure gauges would require two high pressure hoses. However using a hoseless air integrated computer reduces the number of hoses coming out of a regulator and makes the diver more streamlined (less things hanging off of the regulator).
Three small problems exist with this type of pressure sensing system. First, the transmitter can be interfered with by the electrical disturbance of powerful strobes. Divers taking a lot of pictures using strobes may experience a winking out of the air pressure data. The second problem is that the transmitter is rather bulky and depending on the layout of the ports on your regulator, you may not be able to install the transmitter and other low pressure hoses at the same time
The third problem is that if something were to impact the rigid transmitter (e.g. hitting a door overhang when penetrating a wreck), it could theoretically shear off resulting in a high pressure leak from your regulator.

Non air integrated computers

These computers do not measure tank pressure and so will only display no-decompression time limits. Because they do not need to be linked to a high pressure hose on your regulator, these computers may be in the form of modules that can be popped into most gauge consoles or they may be in the form of wrist or BCD mounted units. These computers are very convenient especially if wrist mounted since they can be carried with traveling divers and used with any kind of equipment without requiring installation into a console or a regulator. These computers can also be brought into a dive boat after a dive for the purpose of logging the dive without the need for separating the regulator from the rest of the gear and bringing the whole set up inside

Features of dive computers

Whichever computer you choose should be governed by the type of diving you are doing. Price should not be your least concern as this can become a critical component of your dive gear. Reliability, durability and accuracy come at a price and you will thank yourself for choosing to get what you need and not necessarily what you can afford.

- **User replaceable batteries** - cheaper to operate and if you are diving away from home, you can bring spare batteries with you. Keep in mind that if the batteries in a dive computer fail and you have already done some recent repetitive dives, this residual nitrogen info will be lost during the battery change. It is recommended that you cease diving for 48 hours if you change the batteries under these conditions so that upon recommencing diving, the computers residual nitrogen data will be fairly accurate for your body's physical state
- **Sturdy housing** - some computers resist pressure through the use of oil filled interiors. The housing though for these units are fairly weak and can be damaged through impact. Housings that resist water pressure through the strength of the housing tend to be more rugged. However all computers should be treated with care as they were not meant to be tossed around
- **Large displays** - computers display a lot of information in a compact display. The larger the display, the less cluttered the display of readings and the easier to view the readings. When under the effects of narcosis, large displays are much easier to read especially at a glance.
- **Color coded readings** - some computers show numeric values for readings as well as a color coded bar graph for stuff like nitrogen absorption and air pressure. These bar graphs tend to be easier to read than numeric readings especially with the color coding.
- **Decompression algorithm range appropriate to your dive profile** - some cheaper computers use a standard algorithm that ends at moderately deep limits. However deep trimix or heliox divers doing decompression may opt for a computer with a very deep algorithm. Computers taken beyond their algorithms max depth will result in the computer switching to gauge mode and not returning decompression status information
- **Nitrox compatible** - some computers allow the diver to dial in nitrox mixes. They will then alter their estimate of decompression status for the mix and also return oxygen exposure readings and exceeding max depth for the mix warnings.
- **Multiple gas mix decompression compatible** - most nitrox computers are quasi-tech computers and very advanced recreational units. Serious deep technical diving involves the use of multiple mixtures of breathing gases. At each gas

switch, the computers algorithm would have to adjust in order to remain fairly accurate. Some computers can handle 2 or more gas switches. However most nitrox compatible computers assume that the gas mix you dial in is what you will be using through the entire dive. These computers therefore will give you faulty readings if you are using multiple gas mixtures.

- **PC downloadable** - some computers can transfer the recorded information to an IBM PC. The software can then keep a record of your dives which includes dive profiles of each dive. This information is useful for serious technical divers who want to analyze each step of their dive profiles.
- **Auto-activation** - some computers automatically activate upon contacting salt water. These computers have electrodes on their surface. Current that passes through the completed circuit (electrode to water to electrode) then triggers the device. Other computers require the diver to physically activate them on the surface at which point they will self-calibrate and then go into standby mode waiting to be activated by increasing water pressure. Auto-activated computers are great for divers who occasionally forget to check to see if their computer is on because a manual activated one that has not been activated, requires the diver to surface in order for the unit to turn on, calibrate and then become ready to operate. On the other hand some users have difficulty retrieving data from auto-activated units because data is retrieved by licking ones fingers and completing the circuit between specific electrodes. The manual activation computers though are easier to get information out of because there are 1 or 2 buttons to push in order to query the unit.
- **Backlighting** - backlit units tend to be more useful during night dives or deep dives (where sunlight does not penetrate). These units allow viewing without the use of lights which avoids the risk to momentary blindness from the glare of dive lights reflecting off of the face of the computer. Keep in mind that the use of backlighting also increases the rate of battery drain.
- **Audible warnings** - some computers will give audible beeps when the computer registers warnings or violations. These can be useful to inattentive divers who infrequently check their gauges. However neoprene hoods tend to muffle the sound of these audible warnings. Audible warnings that continue to beep also tend to drain batteries much quicker than if the unit is set to operate silently.
- **Metric or imperial units** - some computers can be switched to read either units. This feature may be useful if for example a travelling tech diver doing decompression is loaned a deco table in units that is not normally what they use. To illustrate a Canadian diver who is used to reading depth in feet, travelling to Switzerland may get a hold of a metric deco table. Without being able to convert the readings in this situation can make a decompression profile rather difficult.
- **Full decompression obligation information** - some computers will only tell you where to stop and when to go to the next stop. These computers do not give the diver any indication of how long they have to remain at the stop. This can be unnerving as a diver has no clue if their air will run out before their obligation is complete. Other more expensive units may use a bar graph or numeric time indication of how long a diver must remain at a given deco stop. This type of

computer is more useful in terms of determining the total decompression obligation for regular decompression divers.

- **Altitude algorithms** - some computers will adjust to take into account altitude for divers who do a variety of diving including mountain lakes.
- **Fly time timers** - most computers will display a countdown timer from the time of your last dive to the time when it should be okay for you to board a plane.
- **Multiple languages** - this is more a frill than a required feature. However if you have visiting friends from another country who wish to use your computer, the multi-language capacity can be a useful feature.
- **Multiple dive day logging** - some computers can save the information from more than one dive. However only some computers can record the dive information from more than one day. For example non-multiple dive day logging computers used on a second day of diving will erase the dive profiles of the previous day's diving and replace this info with the current profiles. Only the residual nitrogen information will be retained over multiple days of diving in this kind of unit.
- **Multiple tissue compartment models** - computers monitoring more tissue compartments will generally be more accurate in decompression status estimates than computers that only follow a few compartments
- **Conservativeness** - it is difficult to say for certain which computer is more conservative than another but I have seen first hand that my computers tend to be more aggressive than my buddy's computer given a specific dive profile. However, conservative is good because it is best to spend less time underwater and be able to return another day than to spend more time underwater and end up in a recompression chamber.
- **Individual coded transmitters for hoseless air integrated computers** - if a hoseless computer cannot be set to identify a specific pressure transmitter, the use of more than one of this kind of computer may result in cross talk between transmitters and computers. This obviously would result in the display of faulty information.

There are some other features that computers will offer but for the most part the above ones are key ones to look out for when selecting a computer.

Types of dive computers

There are ALLOT of types of dive computers. Just about any manuffacturer of diving equipment has his own brand of dive computer.
Here are some of the producers: Uwatec/Scubapro (with their Aladin series computers), Sunnto, Cressi sub, Genesis, Aeris.

The following table shows some of the computer models, the companies that produce them and some features

Make	Model	Total Time to Surface	PC Interface	Variable %02 (Nitrox)	Air-integrated	Comments
Suunto	Companion	no	no	no	no	-
Uwatec	Aladin Sport	no	yes	no	no	adaptive deco prog
Oceanic	Prodigy	yes	no	no	no	user-replaceable batteries
Suunto	Favor	yes	no	no	no	-
Cochran	Captain	yes	no	no	no	-
US Divers	Matrix	yes	no	no	no	wrist model
Oceanic	Data 100	yes	yes	no	no	100m depth
Hydrotech	Data	yes	yes	no	no	user-replaceable batteries
Orca	Pilot Air	yes	yes	no	no	user-replaceable batteries
Oceanic	Data Plus	yes	yes	yes	no	illuminated display
US Divers	Matrix Combi	yes	no	no	no	with pressure gauge
Hydrotech	Data Nitrox	yes	yes	yes	no	cnsO2 & ppO2 warnings
Orca	Pilot Nitrox	yes	yes	yes	no	up to 50% O2 + 1.8 bar ppO2

Make	Model	Total Time to Surface	PC Interface	Variable %02 (Nitrox)	Air-integrated	Comments
Suunto	Solution Alpha	yes	yes	no	no	logs 25hr diving
Uwatec	Aladin Pro	yes	yes	no	no	adaptive deco prog
Ocean Reef	Ocean 01	yes	yes	yes	no	auto back light
Orca	Pilot Air Audio	yes	yes	yes	no	audio
US Divers	Matrix Master	yes	yes	no	no	"back light, pressure gauge"
Aqua-Lung	Monitor 2+	yes	yes	no	no	big display
Oceanic	Datamax Pro	yes	no	no	hose	user-replaceable batteries
Suunto	Favor Air Lux	yes	no	no	hose	back light
Suunto	Solution Nitrox	yes	yes	yes	no	back light
Mares	Guardian	yes	yes	no	no	"back light, pushbuttons"
Orca	Pilot Audio Nitrox	yes	yes	yes	no	audio
US Divers	Scan 4	yes	no	no	hose	user-replaceable batteries
Cochran	Commander	yes	yes	no	radio	-
Suunto	Eon 250	yes	yes	no	hose	logs 25hr diving
Uwatec	Aladin Pro Nitrox	yes	yes	yes	no	adaptive deco prog
Suunto	Eon 350 Lux	yes	yes	no	hose	back light
Uwatec	Aladin Air	yes	yes	no	hose	adaptive deco prog
Cochran	Commander Nitrox	yes	yes	yes	radio	up to two gas changes
US Divers	Scan 5	yes	yes	no	radio	"back light, user-repl. batt."
Oceanic	Data Trans	yes	yes	no	radio	illuminated display
Uwatec	Aladin Air X	yes	yes	no	radio	adaptive deco prog
Aqua-Lung	Monitor 3	yes	yes	no	radio	big display

Make	Model	Total Time to Surface	PC Interface	Variable %02 (Nitrox)	Air-integrated	Comments
Dive Rite	Bridge II	yes	yes	yes	no	up to 50% O2
Uwatec	Aladin Air X Nitrox	yes	yes	yes	radio	adaptive deco prog
Cochran	Nitrox Nemesis II A	yes	yes	yes	radio	up to three gas changes

More about three of these computers, study and text by Rodale's Scuba Diving magazine.

Aeris 500 AI

Strengths

Easy to see, read and understand; Clear graphs with three-color highlighting; Easy adjusting of NDLs at any time with a bar graph; Handles multilevel and repetitive diving well; Excellent backlighting for both surface and underwater use; Multiple user settings that are easy to use; Good instructions and prompt card; Oxygen default in nitrox mode can be turned off; Audible alarms can be turned off; Has user-adjustable sampling rate for dive profiles; Makes use of alternate screens; Displays both remaining gas time and NDLs at the same time; Has a turnaround point alarm.

Weaknesses

Time to fly is an arbitrary countdown. Some letters, symbols and numbers are very small. Building on the success of other Aeris dive computers, the 500 AI adds several significant features to this already strong line of dive computers, including the dependability of hose-mounted gas integration and the ability to display both gas time and NDLs at the same time. Of course, much of the 500 AI' s easy, clear usage comes from the color-highlighted graphs for nitrogen, oxygen and ascent rate.

Other positive features include providing total ascent time when in decompression; gas time remaining that provides for ascent time, any decompression and your preset reserve; extensive data in the log function; and a quick high-pressure disconnect so you can separate the computer from your regulator.

Also available are lens protectors, retractors and clips, plus a compass can be added to the 500 AI.

Usage Notes

- If it has been over two hours since the last dive, you need to reactivate the 500 AI, even if there is information, such as time to fly, on the screen.
- The 500 AI counts dives by dive day, so you will have several dives of the same number, but each dive will also be labeled with the date and time of entry.

- All Aeris dive computers are calibrated for salt water below 2,000 feet elevation and for fresh water at higher altitudes.
- By changing the user-adjustable sampling rate for the dive profiles, you can increase the PC download memory to 254 hours, but of course with far less detail.
- If a violation occurs, the 24-hour lockout is from the time of last use, not from the time of the violation.
- The time to fly is an arbitrary countdown, but you can use time to desaturation as time to fly, if you wish.
- Even though the owner's guide tells you that decompression is an emergency, and then tells you how to decompress, decompression is not an emergency.

Aqua Lung/SeaQuest Cobra by Suunto

Strengths

Compact, small size; Intuitive bar graphs with three-color highlighting; Excellent backlight for both surface and underwater use; A great wealth of features and functions; User-friendly for such a feature-rich computer. High degree of adjustability; with both personal and altitude settings before the dive, and the use of graphs during the dive; Provides for both mandatory and optional safety stops; Wealth of user settings; User-selected gauge mode for special tech situations; Displays both remaining gas time and NDLs at the same time; Only Suunto computers can scroll dive profiles without a PC; Makes use of alternate screens; Excellent decompression mode; Has a bookmark feature to mark events during the dive; Most extensive memory and dive history available among today's dive computers; with 36 hours of logged details[7].

Weaknesses

If violated, goes into gauge-only mode for 48 hours; Nitrogen and oxygen share the same bar graph; Ascent rate indicator is not "buffered," so it shows fast ascents too easily.

The Suunto Cobra packs the most features and functions into a small space of any dive computer we have ever tested. The bringing together of three push buttons with water contacts, graphs and color highlighting, on-screen prompts, dependable hose mounting and the most extensive memory available, make this an outstanding dive computer.

Additional positive features include:

- Oxygen default to 21 percent after two hours of non-use.
- The decompression mode is continuous, so as you ascend, the ceiling moves progressively upward, giving you credit for outgassing and providing an hourglass symbol for the optimum deco zone.
- During decompression, the total ascent time is also displayed.
- The PC sampling rate can be set by the user.

[7] 36 of logged details was the most for a while ago. Now the new Uwatec Aladin computer stores 99 hours of logged details (6/28/2002)

The Cobra is more conservative than older Suunto dive computers. And it can be set to be even more conservative by the use of the personal and altitude settings. The instruction manual states that "the no-decompression limits ... (in the most liberal setting) ... are slightly more conservative than those permitted by the U.S. Navy tables." In fact, the limits range between 56 percent to 80 percent of the Navy tables, depending on depth within the recreational diving range. The leading scientists in the decompression field all agree that the Navy no-decompression limits should be reduced, and Suunto's algorithm does just that, therefore reducing the risk. But by making the Cobra even more conservative with the personal and altitude settings you can reach a point of impracticality: these settings can reduce the no-decompression limits to between 22 and 40 percent of the Navy tables.

Usage Notes

- The Cobra is set for salt water.
- Logged dives are numbered in series until the no-flying time reaches zero. So there will be multiple dives with the same number, but each dive is also identified by date and time.
- Fast ascents can cause a "Mandatory Safety Stop," therefore, you should slow down or stop; if you do not, the no-decompression limits of the next dive will be reduced.
- Take the instructions and prompt card with you on dive trips, as it can be tricky to remember all the button pushing sequences if you do not use the Cobra frequently.
- The nitrogen loading bar graph indicates the time available at depth, not the total impact of the nitrogen loading, as other dive computers do.
- Time to fly is 12 hours plus desaturation time.

The excellent safety stop feature can confuse dive guides who are not familiar with it; so tell your dive guide about it before the dive.

Scubapro/Uwatec Aladin Air Console, Air Z& Air Z O2

Strengths

Clear and easy-to-read displays; Time-to-fly actually calculated and displayed; Also provides desaturation time; Excellent dive profile with PC interface; Long-life batteries; Excellent battery indicator with reserve; Variable ascent rate indicator; More realistic approach to decompression; Gas time remaining and NDLs both displayed at the same time.

Weaknesses

Complete lockout, no gauge mode, no access without a PC; Some settings and data are accessible only with a PC; No planning mode provided in the Air Z O2; Electrical contacts are not labeled.

Even though these three Uwatec Aladin dive computers have very different capabilities, they operate on the same basic algorithm with the same fundamental functions. The Air Console uses a hose, while the Air Z and Air Z O2 are both hoseless. The Air Console and Air Z do not have nitrox functions, while the Air Z O2 does. The Air Z O2 is actually a very sophisticated, high-tech dive computer that can also be paired with an Uwatec OXY-2 (SCR O2) for monitoring the oxygen function of a rebreather. The Air Z and Air Z O2 replace the Air X, Air X Nitrox and Air X O2 in the Uwatec Aladin line.

Other positive features of these computers include:

- Log book and dive planning functions are easy to access.
- Ascent time is provided when in decompression.
- The Air Console has a quick high-pressure hose disconnect on the console end, so it can be removed from the regulator.
- The Air Console also can be fitted with a compass.
- The data displayed on the Air Console is all on the same surface, making it easier to read.
- The PC interfaces provide for 37 logged dives and 175 to 200 minutes of dive profiles, but this can be increased with the use of the optional Memo Mouse to nearly 60 hours of profiles.
- The Air Z and Air Z O2 both have backlights, plus removable/replaceable screen guards.
- The Air Z O2 has excellent oxygen warnings.
- Both the Air Z and Air Z O2 will work without the transmitter, but, of course, will not then display the gas function.
- The oxygen function of the Air Z O2 does not default.

Usage Notes

- The reserve gas setting can only be made with a PC and uses certain odd increments—435, 508, 580, etc. This is due to the calculations being done in metric, but displayed in imperial units.
- A rapid ascent can cause a decompression stop, and, if not heeded, will cause a violation and lockout.
- After the 24-hour lockout period, a desaturation penalty can be added by the computer program for as much as 72 hours.
- The variable ascent rate indicator (faster when deeper and slower when shallower) uses a percentage display, but as it has no "buffer," it jumps around a good deal.
- In the dive plan mode, there is a dive simulator that allows you to change the surface interval and plan no-decompression or decompression dives.
- There are no user adjustments, but Uwatec computers are programmed with a self-adjusting function that increases the conservatism based on temperature, work load, ascent rates and dive profiles.
- The Air Z O2 can be programmed for oxygen from 21 to 99 percent in 1 percent increments.
- Uwatec computers are set for fresh water; therefore, they read 3 percent deeper in salt water; 100 feet reads as 103 feet, etc.

Having no push buttons, Uwatec dive computers do not have alternate screens during the dive mode and are limited as to the data that can be viewed and the settings that can be made on the surface without a PC.

The new Uwatec computers

In 2002 Scubapro Uwatec[8] announces another major addition to the Uwatec range of dive computers with the Smart PRO and the Smart COM. These computers include new features such as the display of the ambient temperature[9] and infrared transmission of the dive data to a personal computer for post dive analysis with Uwatec SmartTrak software. The Smart Pro and Smart Com have display screens that are 35% bigger than the previous generation of computers, already well recognized for their easy to read graphics.

These two new computers are also a major step forward in the technology of diving. The most important enhancement is to the algorithm in these new products, which helps the diver dive in a manner that minimises the long term effects that can occur as a result of diving. To understand how Uwatec Smart Dive Computers work to reduce long term diving symptoms we must first understand microbubbles, how they are measured, their effects and how they can be eliminated.

Microbubbles may be a precondition for the formation of larger bubbles that can lead to decompression illness. Microbubbles usually present no visible symptoms to the diver. Divers who conduct repetitive dives even within the standard no decompression limits have been proven to produce microbubbles. Also, divers who have been diagnosed with PFO (Patent Foramen Ovale – a hole between the two chambers of the heart) are susceptible to microbubble build up.

With two additional letters, the Buhlmann adaptive model has been expanded to be called the ZH-L8 ADT MB. These stands for microbubble, because the low bubbling computers from Uwatec called Smart PRO and Smart COM, can be programmed for microbubble suppression.

A diver can choose from any one of 6 different levels of microbubble suppression from L0, where the suppression is the standard level of suppression in the Buhlmann Algorithm to L5 which is recommended for divers with PFO.

[8] From Uwatec website: www.uwatec.com
[9] Display of the temperature – finally, until now you could see the temperature only when you downloaded the dive on the PC. Imagine the embarrassment when a student asks “So, what was the water temp?”

Smart COM features

- Protective screen shield

- Illuminated display

- Auto Turn On/Off

When it's immersed in water a Smart computer switches on automatically, and immediately moves into dive mode. When it is switched on manually, all data screens are displayed for 5 seconds. At six seconds the computer will change into ready mode.
Five minutes after a dive is completed the computer goes into sleep mode and does not display any information. The computers are briefly activated every minute to measure atmospheric pressure. When a change in atmospheric pressure is recognized, the display is activated to surface mode for three minutes.

- Displays tank pressure - bar (psi)

The Smart Com displays tank pressure in the lower display. The tank pressure is also used for the calculation of the remaining bottom time (RBT) and the workload

- User adjustable tank reserve for RBT-calculation

Air reserve, which should be remaining in the tank after a dive. 30-120 bar or 400-1700 PSI. Default value: 40 bar or 600 PSI

- User adjustable Microbubble Suppression

The Smart dive computer allows the diver to manually select one of 6 Microbubble suppression levels. Level zero offers the standard microbubble suppression that is included in the ZH L8 ADT algorithm.
Levels one to level five offer varying additional levels of suppression with level 5 offering maximum suppression. A diver who is diagnosed with a Patent Foramen Ovale (PFO) is recommended to dive on level 5, as are divers who a doing a lot of repetitive diving

- Auto altitude compensation 0 - 4,000m (13,000ft)

Even while asleep, a Smart dive computer is monitoring atmospheric pressure every 60 seconds, only switching on the dive computer when a new altitude sector is reached. There are four altitude sectors ranging from 1,000m (3,000ft) up to 4,000m (13,000 ft)

- Altitude adaptation time

Usually, we breathe oxygen at about one bar air pressure (which is the ambient pressure at sea level). Air is 21% oxygen and 79% nitrogen so that 21% of the air pressure (0.21bar/3.05psi) is oxygen partial pressure and 79% (0.79bar/11.45psi) is nitrogen partial pressure. At 1,000 metres (3,280 ft), air pressure is reduced to about 0.9bar /13.05psi and therefore, the partial pressures of oxygen and nitrogen are also

reduced to about 0.19 bar / 2.75psi pO2 and 0.71bar/10.30psi pN2. The body has to "outgass" the excess 0.08bar/1.15psi of nitrogen. As a matter of a fact, moving to a higher altitude is a decompression to a lower pressure and it takes the body about 18 to 19 hours to desaturate the surplus nitrogen. The time needed to adapt to the new partial pressure of nitrogen is called adaptation time.
The engineers designing Smart dive computers considered this adaptation time as an integral part of the algorithm for altitude diving. Therefore, even while they're asleep a Smart is monitoring for changes in atmospheric pressure.
Air pressure is measured every minute and classified in four different sections. These sections are displayed on the screen as small mountains. Depending on previous dives and the actual ambient air pressure, the decompression model calculates the adaptation time (or desaturation time to equalize the nitrogen pressure in the body to the nitrogen partial pressure in the ambient air).
The adaptation times depend on the "saturation history" of the diver and the speed of altitude changes. If we assume that there was no previous dive, the adaptation time is about:

18 to 19 hours for altitude section 1 (ambient pressure above 905mbar / 13.12 psi)
26 to 27 hours for altitude section 2 (ambient pressure above 815mbar / 11.81 psi)
32 to 34 hours for altitude section 3 (ambient pressure above 725mbar / 10.51 psi)

If the diver returns to a higher air pressure (lower altitude), we have a reversed situation. This situation is similar to a shallow dive, because the body has to saturate with the excess nitrogen in the air. Of course, the body has also to adapt to this new situation, but the Smart will not display an adaptation time because the adaptation time of the Smart dive computers has the meaning of a desaturation time. A desaturation time is only displayed, if at least one of the tissues is outgassing.

- Displays altitude sector

Even while asleep, a Smart dive computer is monitoring atmospheric pressure every 60 seconds, only switching on the dive computer when a new altitude sector is reached. There are four altitude sectors ranging from 1,000m (3,000ft) up to 4,000m (13,000 ft)

- Prohibited Altitude Advice

1st Figure: Mountain with 4 bars, 850 m / 2790 ft
2nd Figure: Mountain with 3 bars in the top, 1650 m / 5413ft
3rd Figure: Mountain with 2 bars in the top, 2650 m / 8694ft
4th Figure: Mountain with 1 bars in the top, 4000 m /13120 ft
To minimise Microbubble formation, the Smart shows at the surface the altitude ceiling that the diver is prohibited from exceeding, following a dive. Useful for divers who dive in mountainous regions, this is displayed as a flashing altitude segment which corresponds to the altitudes displayed above, and is subject to the preset Microbubble suppression setting in the Smart.

- Nitrox Dive planner

The dive planner allows the diver to plan a dive for any Nitrox mixture up to and including 100% O2. It considers the maximum depth (including the Maximum

Operating Depth) for a given mixture, the best mix for a given depth for a given mixture, the maximum dive time and the CNS 02% at a given depth. It also considers the residual nitrogen levels from a previous dive.

- Dive depth 0-120m (0-395ft)

Starting from a depth of .5 meter (1ft) current depth is continuously monitored and updated in .1 meter increments; depth and dive time, maximum depth and the no stops time. Also the temperature affected tissue saturation is calculated and the no stops time and the decompression requirements are determined.

- Display ambient and water temperature[10]

The ambient temperature is constantly displayed and monitored as an input into the ZH - L8 ADT MB algorithm

- Dive time

Starting from a depth of .5 meter (1ft) current depth is continuously monitored and updated in .1 meter increments; depth and dive time, maximum depth and the no stops time. Also the temperature affected tissue saturation is calculated and the no stops time and the decompression requirements are determined.

- Maximum depth

The maximum depth is only displayed if it exceeds the current depth by more than one metre (3 ft). This prevents frequent changes of the maximum depth when diving in the vicinity of the maximum depth.

- No stop time

- Adaptive decompression model Bühlmann ZH-L8 ADT MB

The ZH-L8 ADT MB decompression model considers eight body tissues as well as the diver's conduct and the ambient conditions. This allows for an even more accurate prediction of the likelihood of decompression sickness. One specific example of conduct considered by the computer where a diver misses a decompression stop and spends less than three minutes on the surface. A missed decompression stop can cause the formation of microbubbles and massively increases the risk of decompression sickness. In this particular instance, starting at 13.6m (45ft) the diver has been instructed to complete a decompression stop at 3m (10 ft) for 3 minutes. However, because the diver has temporarily ascended to .9 metre (3ft) and failed to complete a decompression stop, the computer has now advised two decompression stops. The first is at 6m (20ft) for 5 minutes and then on completion of this stop the diver is advised to stop at 3m (10ft) for 9 minutes.

- Required deepest deco stop (depth)

The need for a deco stop is indicated when the No Stop time reaches zero and the zero starts flashing. The No Stop indication is now replaced by the "Deco Stop"

[10] Aha, so no more of that “So, how hot do you think it is outside?”

indicator with the dive computer displaying the decompression stop depth 3m(10ft) and the duration of the stop, which is expressed in minutes. If there are multiple stops required (for example 6m(20ft) and then 3m(10ft) then the computer will indicate the deepest stop required. On completion of the final decompression stop, the no stops time goes to 99 minutes.

- Required deepest deco stop (time)

The need for a deco stop is indicated when the No Stop time reaches zero and the zero starts flashing. The No Stop indication is now replaced by the "Deco Stop" indicator with the dive computer displaying the decompression stop depth 3m(10ft) and the duration of the stop, which is expressed in minutes. If there are multiple stops required (for example 6m(20ft) and then 3m(10ft) then the computer will indicate the deepest stop required. On completion of the final decompression stop, the no stops time goes to 99 minutes.

- Integrates level stops and deco stops

Smart is always calculating decompression stops and when a Microbubble suppression level has been selected, it is also calculating the necessary level stops. Should a level stop and a decompression stop coincide, then Smart displays two symbols "Deco" and "Level Stop"

- Remaining dive time at current depth (RBT)

- User adjustable low air warning

- Total time to ascend including deco and level stop data

- Variable ascent rate 7-20m/min (23-67ft/min)

Aladin dive computers are programmed to allow an ascent rate of between 7 m/min and 20 m/min, (23ft/min and 67ft/min) dependent on the depth.

- No stop time is less than 1 minute alarm

- RBT is less than 3 minutes alarm

- RBT less than 0 minute alarm

- High breathing rate alarm (High Air Consumption)

The Smart Com calculates the diver's workload and considers the oxygen fraction of the inhalation gas mix. If a diver has reached a pO2 of 1.5 bar, without workload, the O2 toxicity increases by approximately 1% per minute. In this case if there is a very high workload this value increases 10 fold to 10% per minute. For example if there is no workload the diver could stay for 100 minutes, but with a high workload the time is reduced to 10 minutes. It is therefore important that when the lung symbol appears that the diver relaxes the breathing rate.

- Ignored decompression stop alarm
- Warns if level stop is ignored

- "Cascading" microbubble levels

If the depth of a recommended level stop is exceeded by more than 1.5 m (5 ft) then the Smart cascades down to a lower Microbubble level. The Smart now displays the new level until the end of the dive as well as any new level stops that would normally be expected in the lower level.

- Ascent faster than 110% alarm

- Ascent faster than 140% alarm

- Ascent faster than 160% alarm

- Ascent faster than 180% alarm

- PPO2 max has been reached alarm

- CNS 02 percentage has reached 75% alarm

- CNS 02 percentage has reached 100% alarm

- Missed decompression stop instructions

- Displays on the surface of reduced MB-Level

If the Microbubble level has been reduced during the dive, the indicated Microbubble level will continue flashing for five minutes after reaching the surface.

- Desaturation time

- No fly icon and time

- Surface interval

- Logbook contains 50 hours of diving

- Quantity of air used

- Measures water temperature

- Cautions diver on high microbubble levels

- Long life battery

- Percent of remaining battery life
- User switchable metric/imperial
- User adjustable workload warning
- Easy to change oxygen mix from 21% to 100%
- Oxygen mix percentage display
- Adjustable maximum oxygen partial pressure (ppO2) via SmartTrak
- CNS clock is adjusted by O2 uptake according to workload
- Included Smart TRAK software indicates O2 fraction
- Adjustable backlight durationl
- Adjustable Depth limit alarm via SmartTrak
- Adjustable Premix reset via SmartTrak
- Gauge mode
- Buzzer suppression in Smart TRAK
- SmartTrak compatible - CD included
- Infrared Communication (IrDA) with SmartTrak

Conclusion

What do we need to remember?
Do we need to remember how many tissues Haldane's decompression algorithm uses? Or what is the difference between Haldane's algorithm and Buhlmann's algorithm? Or what are microbubbles or how they are formed? Or how conservative is a particular type of computer? Or what is inside of a computer? Or how it can communicate with a PC?
NO! Absolutely not!

Probably the only things we should remember from this paper/presenttion are:

- Diving with a computer makes your dive safer although DCS can still occur
- Remember that the decompression model is a theoretical one which doesn't include the diver's current condition (although some new computers include workload and temperature in their algorithms). The nitrogen levels are estimations not direct readings from your blood stream.
- Read your computer manual and KNOW your computer. If your computer displays something you can't interpret, there is a problem…
- If you can set your level of conservativness, set it up according to your shape and condition. Don't push the limits
- Follow what your computer is telling you to do. If it tell you that you need a decompression stop and your dive buddy doesn't, listen to your dive computer not to your dive buddy.
- Dive with your own computer. A dive buddy team shouldn't share a computer
- Maintain your computer. Rinse it as soon as you got back from a dive
- Check your batteries and don't ignore the low battery warning
- Buy the most expensive computer you can afford. The new and improved dive computers have some really nice features.

Annexes 1

An explanation Professor A A Buhlmann's ZH-L16 Algorithm

By Paul Chapman

The following is a summary of the decompression algorithm described by Dr A A Buhlmann in the fourth edition of his book "Tauchmedizin" (diving medicine) published in 1995 (only in German). The book contains a considerable amount of other information and is published by Springer-Verlag ISBN 3-540-58970-8. Rumor has it that at the time of writing (November 1999) an English translation is being prepared for publishing, so hopefully, in due course, this document will become redundant.

The algorithm is simply a "recipe" for modeling the behavior of inert gasses, which diffuse in and out of our body tissues when breathed under varying pressures. The intention is that if the recipe models the actual processes in our bodies accurately enough, it can be used to plan dives (and other pressure exposures) with a view to avoiding decompression sickness. It's important to realize that the model is entirely arbitrary in the sense that it in no way represents the actual physical processes which are taking place, it simply attempt to model the real-life results mathematically. This article is intended mainly as a description of the algorithm, not as a complete description of decompression physiology and therefore mentions only physiology principles relevant to the algorithm.

Background

Scottish scientist John Scott Haldane is generally considered the founding father of modern decompression theory. In the last century Haldane experimented on goats in an attempt to find a solution to the problem of "caisson disease", experienced by men working in pressurized bridge and tunnel construction areas. Research suggested that gasses, breathed under pressure by the workers, were diffusing into the body's tissues and when these gasses came out, in the form of bubbles in the body, the workers got caisson disease, or what we now call decompression sickness, or "the bends". Haldane's work led him to consider the body as a group of tissues in parallel. This meant the tissues were all exposed simultaneously to the breathing gasses at ambient pressure, but able to react to them in their own individual ways. No gas transfer from one tissue to another was considered. This principle is still in use and is the basis of many, but not all, current decompression models. The model used in the production of the British Sub Aqua Club BSAC-88 dive tables, for example, used a single block of "tissue" along which gas diffused, while the Canadian DCIEM model uses a range of tissues, but arranged in series

- only the first of a range of tissues is exposed to the ambient pressure and gas diffusion takes place from one tissue to the next. Haldane also noticed that the body could tolerate a certain amount of excess gas with no apparent ill effects. Caisson workers pressurized at two atmospheres (10 metres/33 feet) experienced no problems, no matter how long they worked. These two ideas, gas traveling though the body tissues and the theory of a "tolerable overpressure" formed the basis of Haldane's work. The tricky bit was to model exactly how the gas moved through the body and exactly what amount of overpressure was acceptable and Haldane actually achieved this with considerable success. Others developed Haldane's ideas over the years. In the mid-1960's US Navy Medical Corps Captain Robert Workman refined the idea of allowable overpressure in tissues, discounting oxygen and considering only inert gasses in the breathing mix, such as nitrogen and helium. Workman's maximum allowable overpressure values (what he called "M-values") were more complex than Haldane's, varying with depth and with tissue type. At around the same time Professor Albert Buhlmann was working on similar research at the University Hospital in Zurich. Buhlmann's research spanned over 30 years and was published as a book, Dekompression - Dekompressionskrankheit in 1983. This book, published in English in 1984, made fairly comprehensive instructions on how to calculate decompression available to a wide audience for the first time and therefore Buhlmann's work became the basis for many dive tables, computers and desktop decompression programs. Three other editions were published, the last in 1995, on which this document is based.

Basic Ideas

Due to differences in perfusion (blood flow), diffusion (rate of gas flow from one place to another) and other factors, the inert gasses we breathe are dissolved into our different body tissues at different speeds. Tissues with high rates of diffusion, which have a good blood supply, build up a gas load more quickly. The blood itself, major organs, and central nervous system fall under this heading and we call them "fast" tissues. Other tissues build up a gas load more slowly. Progressively slower tissues include muscle, skin, fat and bone. Many tissues, through good blood supply, are exposed almost immediately to higher inert gas pressures, while others have to wait for gas to reach them by diffusion from other surrounding tissues. In this sense the body tissues are both serial and parallel. Although a fast tissue will build up a higher inert gas load ("on-gas") more quickly when the pressure increases, it will also be able to get rid of that gas load more quickly than a slower tissue when the pressure drops, a process we call "off-gassing" It is assumed that tissues on-gas and off-gas according to the theory of half-times. Many natural phenomena are described this way, including radioactive decay. The idea is that when a tissue is exposed to a higher inert gas pressure, gas will flow into that tissue. After the "half-time" the pressure of gas in the tissue will be half way to equaling the pressure of the gas outside. After a second half-time, the gas pressure in the tissue will have risen by half of the remaining difference (i.e. by a further quarter), making it 75%, or three-quarters, of the way to equaling the external gas pressure. After a third half-time, the rise is 12.5% (87.5% total) and so on. By this method the pressure in the tissue never quite reaches the same level as the surrounding gas, but after 6 half-times, it's close enough and we say the tissue is "saturated". At this point gas will diffuse into the tissue at the same rate that it diffuses out and the tissue experiences no further overall change in gas load. If the pressure then increases (the diver goes deeper), the tissue will begin to on-gas again. If the pressure reduces, the tissue will off-gas, again following the half-time principle. After six half-times, the tissue will again be "equilibrated" with its surroundings. As well as differing for each tissue, half-times will vary for different gasses, since they diffuse at different rates. For real human tissues nitrogen half-times will vary from a few seconds (blood) to many hours. For helium, half-times are thought to be about 2.65 times faster than nitrogen, since helium diffuses more quickly.

If pressure is reduced by too much on a tissue, the gas will be unable to follow the diffusion route, via the bloodstream, back to the lungs and will form bubbles in the actual tissue, leading to many of the symptoms that we know as decompression sickness. So how much pressure reduction is too much? It's been shown by experimentation that faster tissues like blood can tolerate a greater drop in pressure than slower tissues, without bubble formation. One of the challenges to Buhlmann in formulating his algorithm was to quantify this difference in a mathematical formula that could be used to help calculate decompression profiles. We'll look at his solution in a moment.

For his ZH-L16 algorithm Buhlmann chose to split the body into 16 "tissues" and give them a range of half-times, from minutes, through to several hours. It's important to remember that these are not representing any specific real tissues in the body and the half-times are simply chosen to give a representative spread of likely values. They do not represent actual tissues, or the actual half-times for any particular tissue. For this reason the often-used description of the 16 sections as "tissues" is confusing and they will be referred to in future as "compartments". Buhlmann named his algorithm from Zurich (ZH), limits (L) and the number of M-value sets (16).

When exposed to pressure, each compartment on-gasses according to it's given half time, so at any point we can calculate how much inert gas pressure exists in each compartment. There's a standard mathematical form for half-time calculation, Buhlmann made some additions to it to make a complete before/after formula for the inert gas pressure in any given compartment after any given exposure time. Here's the formula as published in Tauchmedizin, the names of the constants have been changed to make them more understandable in English, but the formula's the same:

$$\mathbf{P}_{\text{comp}} = \mathbf{P}_{\text{begin}} + [\ \mathbf{P}_{\text{gas}} - \mathbf{P}_{\text{begin}}\ ] \times [\ 1 - 2^{-\mathbf{t}_e/\mathbf{t}_{ht}}\ ]$$

Where:

$\mathbf{P}_{begin}$	Inert gas pressure in the compartment before the exposure time in bar
$\mathbf{P}_{comp}$	Inert gas pressure in the compartment after the exposure time in bar
$\mathbf{P}_{gas}$	Inert gas pressure in the mixture being breathed in bar
$\mathbf{t}_e$	Length of the exposure time in minutes
$\mathbf{t}_{ht}$	Half time of the compartment

Here's an example: A diver descends from the surface to 30 metres on air and waits there ten minutes. The partial pressure of nitrogen in the breathing gas ($\mathbf{P}_{gas}$) is 4 x 0.79 = 3.16 bar. Let's pick a compartment, say number five. The nitrogen half-time for compartment five ($\mathbf{t}_{ht}$) is 27 minutes. The nitrogen partial pressure in compartment five on the surface ($\mathbf{P}_{begin}$) is 0.79, assuming the diver hasn't already been diving or subject to any altitude changes. The length of the exposure ($\mathbf{t}_{e}$) is ten minutes. Plugging these values into the equation, we get:

$$\mathbf{P}_{comp} = \mathbf{0.79 + [\ 3.16 - 0.79\ ]} \times \mathbf{[\ 1 - 2^{-10/27}]}$$

Do the bits in brackets first:

$$\mathbf{P}_{comp} = \mathbf{0.79 + 2.37} \times \mathbf{0.226}$$

Do the multiplication first, then the addition:

$$\mathbf{P}_{comp} = \mathbf{1.33}$$

So the partial pressure of nitrogen in compartment five of our diver would be 1.33 bar. In reality, the diver couldn't have made an instantaneous descent to 30 metres and would have been taking on gas during the descent as well. We could average the pressure during the descent and repeat the above calculation to get an idea of the extra gas, or simply repeat the calculation many times at short intervals during the descent, a computer makes this easy.

You can repeat this calculation, of course, for all the other compartments, you just need to know the half-times (see table 1), again a computer is the ideal tool for this job. The beauty of the equation is its versatility. Absolute pressure (not depth) is used everywhere, as is the actual partial pressure of the inert gas being breathed, so we can ascend or descend to/from any pressure, breathe any gas, change gasses, go flying after diving, stay on the surface, do a repetitive dive or anything we can think of.

Table 1 - ZH-L16A Half-times, "a" and "b" values for nitrogen and helium

Compartment	Half-time N2	N2 a Value	N2 b Value	Half-time He	He a Value	He b Value
1	4	1.2599	0.5050	1.5	1.7435	0.1911
2	8	1.0000	0.6514	3.0	1.3838	0.4295
3	12.5	0.8618	0.7222	4.7	1.1925	0.5446
4	18.5	0.7562	0.7725	7.0	1.0465	0.6265
5	27	0.6667	0.8125	10.2	0.9226	0.6917
6	38.3	0.5933	0.8434	14.5	0.8211	0.7420
7	54.3	0.5282	0.8693	20.5	0.7309	0.7841
8	77	0.4701	0.8910	29.1	0.6506	0.8195
9	109	0.4187	0.9092	41.1	0.5794	0.8491
10	146	0.3798	0.9222	55.1	0.5256	0.8703
11	187	0.3497	0.9319	70.6	0.4840	0.8860
12	239	0.3223	0.9403	90.2	0.4460	0.8997
13	305	0.2971	0.9477	115.1	0.4112	0.9118
14	390	0.2737	0.9544	147.2	0.3788	0.9226
15	498	0.2523	0.9602	187.9	0.3492	0.9321
16	635	0.2327	0.9653	239.6	0.3220	0.9404

Now we know the inert gas pressure in any given compartment at any time, we need to know the depth (or actually the pressure) that we can ascend to safely. We already mentioned that this would vary for each compartment, with faster compartments tolerating a greater pressure drop than slower ones. Buhlmann decided that the amount of pressure drop that a certain compartment could tolerate without bubble formation could be mathematically linked to it's half-time. He first derived two factors, which he called "a" and "b" from the half-time (so each compartment has it's own pair of a and b values), then he used these factors to calculate the pressure that we could ascend to. The a and b modifiers are obtained from the following formulae:

$$a = 2 \times t_{ht}^{-1/3}$$
$$b = 1.005 - t_{ht}^{-1/2}$$

Where t_{ht} is the half-time for the compartment. For example, the half-time for compartment 5 is 27 minutes, so $a = 2 \times 27^{-1/3} = 0.6667$ and $b = 1.005 - 27^{-1/2} = 0.8125$

Remember that the half-times vary for different gasses, so each gas will have it's own set of half-times, a and b values (see table 1)

Now we know a and b, we can use a formula to calculate the pressure that we can ascend to for each compartment. Here's the formula Buhlmann chose to use:

$$P_{amb.tol} = (P_{comp} - a) \times b$$

Where:

P_{comp}	is the inert gas pressure in the compartment
$P_{amb.tol}$	is the pressure you could drop to
a and b	are the a and b values for that compartment and the gas in question

Using the example above, we found that a exposure for ten minutes to 4 bar pressure (30 metres depth), led to a nitrogen pressure of 1.33 bar in compartment 5 and the a and b values for compartment 5 were 0.6667 and 0.8125 respectively. Plugging these into the above formula (don't forget to do the subtraction in brackets first) gives:

$$P_{amb.tol} = (1.33 - 0.6667) \times 0.8125 = 0.54 \text{ bar}$$

Pressure at sea level is taken to be 1 bar and the above equation shows us that we can actually ascend to a pressure lower than that (i.e. above the surface). In other word's, according to the model, after 10 minutes at 30 metres (4 bar) we could ascend straight to the surface with no bubble formation in compartment 5 assuming we were breathing air. This is a "no-stop" dive, as we'd expect from looking at our dive tables!

If we tried our 30 metre exposure for 50 minutes, we'd find the nitrogen partial pressure in compartment five was 2.5 bar (from the first equation) and our pressure could drop to 1.49 bar. This pressure is just under 5 metres depth, so this is the maximum depth that compartment 5 would allow us to ascend to after 50 minutes at 30 metres.

Using the same depth and time, if we repeat this method for all the other compartments, we'll find different values, for example:

Compartment 3 - Half-time 12.5 minutes, a = 0.8618, b = 0.7222
P_{comp} = 3.01 bar
$P_{amb.tol}$ = (3.01 - 0.8618) x 0.7222 = 1.55 bar (or 5.5 metres depth)

Compartment 10 - Half-time 146 minutes, a = 0.3798, b = 0.9222
P_{comp} = 1.29 bar
$P_{amb.tol}$ = (1.29 - 0.3798) x 0.9222 = 0.84 bar (still above the surface)

Once we've repeated this for each compartment, we cannot ascend any shallower than the deepest of the tolerated depths. In our three-compartment example, this is 5.5 metres. This is called our "decompression ceiling" and the compartment concerned (compartment 3) is said to "control" the decompression at this point. In general, faster compartments will control short, shallow dives. Long shallow dives and short, deep dives will see a shift towards the middle compartments as controllers while long, deep dives will be controlled by the slower compartments. The controlling compartment will often shift during a decompression. For example, a short deep exposure may see the initial ceiling limited by the faster compartments, but as these off-gas quickly the control shifts to the slower, mid-range, compartments. As you can imagine, calculating the gas loads for a sequence of several dives of differing depths and durations is quite involved. Although the maths is actually straightforward, as we've seen, the number of calculations and constant shifting of the controlling compartment and it's associated decompression ceiling make it a great job for a computer.

If we were actually planning a decompression for our 30metre, 50 minute dive, we could ascend right up to the 5.5 metre ceiling, but it's more usual to choose a convenient interval for decompression stops, say every 3 metres, then you'd ascend to the nearest multiple of 3 metres that's below the decompression ceiling. In this example that's 6 metres. At this point the inert gas pressure in the more highly loaded compartments will be above the inert gas pressure in the breathing mix and those compartments will start to off-gas. Other compartments may have inert gas pressures lower than the breathing gas and these compartments will still be on-gassing. We start the half-time calculations again. The formula is identical taking reductions in pressure (ascents) into account automatically. During the ascent the inert gas partial pressure being breathed ($\mathbf{P}_{gas}$) drops, wheras the pressure in the compartment ($\mathbf{P}_{begin}$) hasn't caught up yet, so the [$\mathbf{P}_{gas}$ **-** $\mathbf{P}_{begin}$] part of the equation becomes negative. Don't forget the driving force for the gas diffusion (in the model, at least) is the difference between the inert gas pressure in the compartment and the ambient partial pressure of the inert gas. At 6 metres the PPN_2 in air is 1.26 bar. In our example, the nitrogen pressure in compartments 3 and 5 was 3.01 bar and 1.33 bar respectively. These are both higher than the 1.26 bar ambient PPN_2, so compartments 3 and 5 will off-gas at this decompression stop. The PPN_2 in compartment 10 however has only reached 0.29 bar. This compartment will continue to on-gas at 6 metres depth, although at a slower rate than before because the ambient PPN_2 is lower than at 30 metres. The ceiling will gradually get shallower as the compartments off-gas, eventually reaching our chosen next stop depth (3 metres). At this point we ascend to this depth and start the process again, until we reach a point where the $P_{amb.tol}$ for all compartments is less than, or equal to, one and we can reach the surface.

That's all there is to it. Calculations can continue while you're on the surface (compartments continue to off-gas), so we can allow for a surface interval between dives and when we go down for our next dive some compartments may still be partially loaded. This loading will automatically be added to any additional gas gained during the dive, adjusting the decompression accordingly. Flying or ascending to altitude is just a matter of "ascending" through the atmosphere. The calculations are the same, it's just that the pressure changes may take thousands of metres of air as opposed to just a few metres of water. If we know the cabin pressure in an airliner (say 8000 feet/2400 metres) we can use this as our ceiling and carry on calculating until we can reach it…this is our "time to fly". The formulas use inert gas partial pressure throughout, so diving with nitrox is automatically accommodated. Likewise trimix (oxygen, nitrogen and helium mixes) and alternative decompression gasses (usually with lower proportions of inert gas) can all be accommodated within the same basic algorithm as long as we know the half times and the a and b values for the gasses. Where multiple inert gasses are used, an intermediate set of a and b values are calculated based on the gas proportions.

Modifications for the real world

Take note that all the above is to be read in the context of referring to the ZH-L16 model, not to our own bodies. Buhlmann carried out a considerable amount of actual testing to validate the ZH-L16 algorithm, but only using nitrogen as the inert gas. The half times for helium were derived from those for nitrogen, based on the speculative idea that the relative diffusivity of the gases was all that mattered. Since the a and b values are further derived from the half times, these also fall under the heading of "educated guesswork". Sadly Buhlmann died before he was able to put his theoretical figures for helium to any extensive tests. It appears that Buhlmann's values for helium may be rather too conservative and for years the result has been that people have assumed that decompressions from helium would be longer than from nitrogen, simply because that was what the formula told us. In fact helium is generally a much more "deco-friendly" gas than nitrogen, being less soluble in our tissues. The rapidly diffusing gas is more prone to bubble formation, requiring control of ascent rates and decompression stops that start deeper than nitrogen. The payback is shorter shallow stops and a reduced overall time for decompression.

A huge number of factors affect inert gas absorption, elimination and our susceptibility to decompression sickness. Some of these factors we know, some we guess at and some, no doubt, remain to be discovered. Among the first two categories are:

Repetitive, yo-yo, reverse and bounce dive profiles
Rapid ascents
Missed decompression stops
Heavy workloads
Exercise, or lack of, during decompression
Cold
Flying after diving
Poor physical conditioning
Inter-pulmonary shunts
Drug use (including alcohol)
Dehydration
Age

In an attempt to address some of these factors, Buhlmann suggested and made several modifications to his algorithms. For dive table production, the “a” values were altered to be a little more conservative, principally in the middle compartments, resulting in a variation of the algorithm called ZH-L16B. Further variations to both middle and upper “a” values are used in ZH-L16C, intended for use in dive computers, where the exact depth and time tracking removed some of the natural conservatism associated with table use. Attempts to include the effects of some of the other predisposing factors mentioned above led to the ZH-L8 ADT “adaptive” algorithm, implemented on the latest Aladdin dive computers.

Dive computers and planning programs for personal computers, typically implement these modifications and/or variations of their own in an attempt to make the dive profiles they generate more realistic, or more usually, just “more conservative”. Modifications include planning dives deep and/or longer than actual, further tweaking of the a and b values, limiting compartment over-pressure ($P_{amb.tol}$) to a percentage of the calculated value, changing the amount of inert gasses by some factor, using longer half-times for the off-gassing phase of the profile, adding more compartments and any number of other factors and combinations of factors.

It’s interesting to note that the model clearly tells us that there’s no such thing as a “no-decompression” dive. We begin to on-gas immediately we descend. What we call a no-decompression dive is really one where the ceiling is still above the surface. As the dive goes on and the ceiling reaches the surface, we can factor in the ascent rate and gain a few more minutes “no-decompression time”.

Modern Ideas

The reality is that we will never get truly accurate decompression tables or computers. The chaotic nature of our own physiology means a certain amount of conservatism will be required. The best we can generally hope for are ones that work most of the time, for most people. It is highly likely that current tables are much too conservative for some individuals, while being overly liberal for others. As our knowledge of decompression physiology improves, this holds out the hope of tables, or more likely computer programs, tailored to some extent for the individual. Organisations such as the Woodville Karst Plain Project, with a large database of extreme dive exposures, and knowledgeable and committed team members, have achieved great advances in this area.

From Doppler studies, we now know that bubbles form in divers after most dives. Although causing no noticeable symptoms, gas elimination from these so-called "silent bubbles" occurs differently from gas dissolved in the blood. A reduction in ambient pressure will cause these bubbles to grow regardless of inert gas diffusion. Buhlmann's algorithm assumes all gas is being eliminated in the dissolved phase (i.e. dissolved in the tissues) and does not take these factors into account. Bubble mechanics formulae such as Bruce Weinke's Reduced Gradient Bubble Model attempt to model gas elimination in the gas-phase (bubbles) as well as dissolved gas.

Finally, helium is becoming accepted as a more deco-friendly gas than nitrogen. As well as the benefits of narcosis reduction, further experimentation holds out the possibility of faster decompressions than were previously thought possible and will probably include the use of helium in decompression gasses as well as bottom mixes. Helium is expensive, which has limited it's use in sport diving, however rebreathers may eventually become reliable and simple enough for the average scuba diver to take advantage of helium mixtures economically and safely.

My thanks to the members of the Woodville Karst Plain Project for providing both valuable information and the inspiration to learn more and do it right.

Annexes 2

How to implement Buhlmann's algorithm on a computer

DIY DECOMPRESSION
By Stuart Morrison

The author accepts no responsibility for any errors contained within this article or injuries or illness arising from using the information contained here, or any applications to which it is put.

To many divers, the decompression information generated by dive computers, tables and PC programs are mysterious and the products of either Einstein-like intelligence or a mysterious cabalistic form of alchemy. The reality is that they are simply the results of some straightforward equations.

The theory behind decompression modelling is very complex, but the calculations themselves are in practice within the realms of every diver. Decompression modelling is not representing what is going on within the body, it is simply a mathematical function which spits out figures which do not kill us. The protocol used to calculate decompression data is known as the algorithm, and there are many base types.

What is decompression?

We cannot breathe underwater so we need to take a breathing gas with us. Oxygen is essential to us, but too much will cause serious physiological problems, too little will not support life – it is a very fine balance and all technical divers should understand that. Oxygen needs to be "diluted" with other gases which are inert (i.e. not required by any physiological process, and not causing any toxic effects). Nitrogen is the easiest choice (air/nitrox) but to avoid narcosis then helium is added too (trimix). Underwater we breathe our gas mixes at pressures higher than atmospheric pressure which causes a certain amount of the inert gas(es) to dissolve into the body's tissues – the longer and/or deeper the dive then the more inert gas which will dissolve. Eventually saturation is reached – the point where no more gas will dissolve regardless of bottom time.

When we return to the surface, the pressure is reduced and the tissues can no longer hold the same amount of dissolved gas. The gas is released and the rate at which this happened controls whether or not the diver suffers from decompression illness (the bends). All a decompression model does is tell the diver how to ascend to the surface.

This article explains DIY decompression theory using the Buhlmann ZH-L16 model, and it is assumed that the diver will be familiar with partial pressures; the differences between saturation, desaturation and supersaturation; haldanean decompression models and half-times; tissue compartments; exponential decay and basic diving physiology. It is recommended that a good text book such as "Deeper Into Diving" by John Lippman is referred to.

The Basics

The Buhlmann ZH-L16 model is the most commonly used because it is the only algorithm which has been freely published with all the needed information in one volume. It is also very well tested, and appears to be reasonably reliable.

This article assumes that the calculations will be done by a computer program and I have included some simple routines which will form the basis of a program. I have written the routines in simple English instructions which should be easy to follow for the non-programmer, and simple to convert to a programming language. These are all based on notes which I have used to write decompression software in both C and Visual Basic.

There should be one unit used throughout. It is important to think in terms of pressure rather than distance. For example, 10msw depth does not mean ten metres distance from the surface but the weight of a ten metre water column. It is important that all pressures are expressed in the same unit, either bar or msw. One atmosphere of pressure can be either 10msw or 1bar. Similarly the partial pressure of nitrogen in air on the surface is either 7.9msw or 0.79bar. Use one unit or the other, do not switch between them.

Water vapour in the lungs plays an important role. Air is 79% nitrogen and 21% oxygen, and at sea level the partial pressure of nitrogen is 0.79bar. You would assume that in the lungs this would be the same but because of the high humidity there the partial pressure of nitrogen is less. We need to correct for water vapour and its partial pressure (Pw) must be subtracted from ambient pressure (Pa):

$$ppN2 = FN2 \times (Pa - Pw)$$

$$ppN2 = 0.79 \times (1 - 0.0567)$$
$$ppN2 = 0.745\text{bar}$$

If we are diving at sea level then Pa = 1. If we are at altitude then Pa will be much less and depends on the height above sea level.

The basic concept is that the body is represented by sixteen tissue compartments, each with the half-times as shown in Table 1. These tissues absorb and release gas throughout the dive. None of the tissues have any connection to any of the others and cannot be affected by any other.

Step 1 – Initialise the Model

The tissue model needs to be initialised. At the surface, breathing air, and not having dived for a while, every tissue in the model will be stable and have the same gas loading. In all the following examples, the tissue gas loading will be represented by Pn (nitrogen loading), Ph (helium loading) and Pt (total gas loading):

Pn = 0.79 x (1 – 0.0567) = 0.745bar

As there is no helium yet:

Ph = 0

So the total is:

Pt = Pn + Ph

Pt = 0.745 + 0 = 0.745bar

This means that all 16 tissues start off with a loading of 0.745bar in them. A common mistake is to forget to initialise the tissues. The program routine would be along the lines of:

Initialise_Tissues:

For All 16 Tissues

Pn = 0.79 * (ATM - WATERVAPOUR)

Ph = 0

Pt = Pn + Ph

where ATM = atmospheric pressure (bar) depending on height above sea level, WATERVAPOUR is the water vapour pressure. For programming I maintain two arrays of
sixteen variables, one array for nitrogen and the other for helium.

Step 2 – The Descent

The next thing to do is to get the depth of the dive. You can assume an instant descent to keep things simple but on deep dives there can be quite a lot of ongassing during depth changes. A normal descent rate is around 30m/min. There is an equation known as the Schreiner equation which calculates the gas loadings for a descent:

P = Pio + R(t - 1/k) - [Pio - Po - (R/k)]e^-kt

Pio = initial ambient pressure minus water vapor pressure

Po = initial compartment inert gas pressure

R = rate of ascent/descent times the fraction of inert gas

t = time interval

k = half-time constant = ln2/half-time

e = base of natural logarithms

You would need to do this for all sixteen tissues:

Descent_Gas_Loadings:

t = Depth / DESCENT_RATE

For Each Tissue Loading:

;; Nitrogen first

Po = Pn [this is the current loading at the start]

Pio = (Depth - WATERVAPOUR) * fN2 [ppN2 in lungs]

R = DESCENT_RATE * fN2

k = log(2) / [nitrogen half-time of this tissue]

Pn = Pio + R*(t - (1/k)) - (Pio - Po - (R / k))* exp(-k*t)

;; Helium next

Po = Ph [this is the current loading at the start]

Pio = (Depth - WATERVAPOUR) * fHe [ppHe in lungs]
R = DESCENT_RATE * fHe
k = log(2) / [helium half-time of this tissue]

Pn = Pio + R*(t - (1/k)) - (Pio - Po - (R / k))* exp(-k*t)

where fN2 and fHe are the fractions of nitrogen and helium (79% = 0.79, 25% = 0.25, etc). Note that all descent rates are positive whereas all ascent rates are negative.

Step 3 – The Dive

Next thing to do is to get the information for the actual portion of the dive spent on the bottom. You need the depth, the bottom time and the gas mix. The above Schreiner equation can be used and the term 'R' can be set to zero and 't' becomes the bottom time. Or you can use a simplified version known as the "Instantaneous Equation":

P = Po + (Pi - Po)(1 - 2^(-t/half-time))

where:

P = compartment inert gas pressure (final)

Po = initial compartment inert gas pressure

Pi = partial pressure of inspired inert gas

t = time (of exposure or interval)

Again, you need to go through every tissue compartment and load it:

Dive_Loadings:

t = [bottom time of the dive]

For Each Tissue Loading:

;; Nitrogen loadings first

Pi = (Depth - WATERVAPOUR) * fN2

Po = Pn [current gas loading in this compartment]

P = Po + (Pi - Po)*(1 - 2^(-t / [N2 half-time for this tissue]))

Pn = P

;; Helium loadings first

Pi = (Depth - WATERVAPOUR) * fHe

Po = Ph [current gas loading in this compartment]

P = Po + (Pi - Po)*(1 - 2^(-t / [He half-time for this tissue]))

Ph = P

For multi-level dives you simply repeat the entire process for every stage of the dive, ensuring that the ascent ceiling is not violated at any stage.

Step 3b – Checking the Ascent Ceiling

The ascent ceiling is the shallowest depth to which a diver can ascend without serious risk of developing DCI. The ascent ceiling also represents the depth of the first decompressions stop (normally rounded down to 3m intervals) and shows if the dive is a no-decompression dive (when the ascent ceiling is zero or negative).

The ascent ceiling is calculated by using the a/b coefficients. Other Haldanean models use m-values which represents the maximum tissue loading for a specific depth which will not produce DCI in that tissue. I find a/b coefficients easier to work with. Each tissue has its own pair of a/b-values, nitrogen and helium. Table 2 lists them. Set A is the original set not intended for practical use, set B is recommended for software and table generation and set C is intended for incorporation into dive computers. The following equation is used to calculate the ascent ceiling for each tissue:

Ceiling = [(Pn + Ph) – a] * b [ceiling is given as an absolute pressure e.g. 2.3bar = 13msw]

where ‘Pn’ is the current nitrogen loading and ‘Ph’ is the current helium loading. Each tissue will have a different ascent ceiling and the deepest ceiling is the one which should not be violated.

There are a/b coefficients for both helium and nitrogen so which one do you use? For a nitrox dive you use nitrogen, for a heliox dive you use helium, but what about trimix? You can either use the nitrogen set which will give a more conservative schedule or you can interpolate the value based on the proportions of each gas load in each tissue.

For example, if a tissue has 2.65bar of nitrogen in it and 1.34bar of helium then the total gas loading is 3.99bar. Nitrogen makes up 66% of the total loading and helium makes up 34% of it. So you would take 66% of the nitrogen a or b value and 34% of the helium a/b value:

a = [a(n2) x Pn + a(he) x Ph] / (Pn + Ph)

b = [b(n2) x Pn + b(he) x Ph] / (Pn + Ph)

where ‘a(n2)’ & ‘b(n2)’ are the a/b values for nitrogen and ‘a(he)’ & ‘b(he)’ are the a/b values for helium.

To calculate the ceiling:

Ascent_Ceiling:

For Each Tissue:

;; Calculate the a/b values

A = ((an2 * Pn) + (ahe * Ph))/(Pn + Ph)

B = ((bn2 * Pn) + (bhe * Ph))/(Pn + Ph)

Ascent_Ceiling[This Tissue] = ((Pn+Ph) - A) * B

Find the deepest ascent ceiling of the 16 values

Critical Ascent Ceiling = Highest Value

Step 4 – Get the First Decompression Stop

The first decompression stops is simply the ascent ceiling rounded to the next multiple of 3m. For example if the ascent ceiling is 11m then the first stop is at 12m, if the ceiling is 19m then the first stop is 21m, etc.

Step 4a – Finding the No Decompression Limits

To find the no decompression limits use the following process:

Initialise the model (Step 1)

Descent loadings (Step 2)

Get the planned depth and gas mix and load the tissues, using a bottom time of 1 minute (Step 3)

Check the ascent ceiling (Step 4)

Keep repeating Step 3 until the ascent ceiling becomes greater than zero (i.e a depth below the surface). The number of 1 minute intervals (iterations) which you have to do to make the ascent ceiling not zero is the no-deco limit for that depth and gas mix.

Step 5 – Calculating the Length of Decompression Stops

In step 4 you get the first deco stop depth. Now you have to use that to calculate the stop times. Normally the stop depths range in 3m intervals (3m, 6m, 9m, 12m, etc.).

You make your current depth the stop depth. You need to repeat step 3 (using the current stop depth as the depth, 1 minute as the bottom time, and the deco gas for the gas mix info) until the ascent ceiling changes to the next stop depth. For example:

…your first stop is 12m, your deco gas is EAN50. You repeat step 3 using these figures (and 1 minute bottom times) until the ascent ceiling changes to 9m (the next stop). The number of iterations (i.e. the repetitions of step 3) indicates the stop length i.e. four iterations means a four minute stop. You then move up to 9m and repeat the process until the ascent ceiling changes to 6m. At 6m you repeat until the ceiling is 3m (or the surface if you want 6m as your last depth) and so on.

The program code would be something like this:

StopCalc:

Get FirstStop [As step 4]

LastStop = [3msw] [or whatever you like]

For Each Stop From FirstStop to LastStop in 3m steps

Get DecoGas [do this at every stop]

StopLength = 0

Until AscentCeiling = ThisStopDepth - [3msw]

Do Stage3(Depth=ThisStopDepth, BT = 1min, GasMix = DecoGas)

StopLength = StopLength + 1

When this loop has ended then the total stop time = StopLength

Move up to the next stop depth and repeat until the surface is reached

The code simply loops through the 1min iterations until the next shallowest stop depth is reached. For a closed circuit rebreather you would need to calculate what gas would actually be in the loop based on the unit's setpoint.

That is basically it. The steps are as follows:

1. Initialise the model based on the altitude
2. Get the depth of the dive and the breathing mix, then calculate what the tissue loadings will be during the descent
3. Get the bottom time of the dive and calculate the loadings based on that.
4. If it is a repetitive dive then repeat (3) again for each stage
5. Calculate the first decompression stop depth
6. Get the deco gas and do 1min loops at the stop depth until the ascent ceiling is equal to or less than this stop depth – 3 or the surface ambient pressure. The number of loops equals the length of the stop
7. If you haven't reached the surface yet then repeat (6) but get a new deco gas and make the stop depth 3m shallower.
8. Print the schedule at the end

If you want a repetitive dive then you just treat it as though it is a dive breathing air for the length of the surface interval and at a depth equal to the ambient pressure at the surface. For the next dive you would miss out Step 1, the initialisation stage and just use the tissue loadings which you are left with at the end of the surface interval.
Simple. The first deco software I wrote had about 150 lines of instructions and took two hours to write. Programming with fancy graphics for Windows takes considerably longer and the original version of XS took around three months to complete.

Safety Factors and Conservatism

It is well accepted that the unmodified Buhlmann algorithm is not conservative enough for actual dive planning. There are a few ways of adding in safety factors.

Proplanner increases the inert gas content depending on the safety factor which you enter.

Older versions of the Abyss assumes that offgassing is slower than ongassing. It also modifies the compartment half-times based on data which the user supplies: fitness, experience, work rate, comfort levels, etc.

Zplan lengthens bottom times before it plugs them into the equations.

How well these work is debatable, and the common thread is that they alter the tissue loadings. Many people feel that this is not the best approach as it simply lengthens the shallowest stops. Any damage will have already occurred by the time you reach 3m or 6m. Starting deco deeper is felt to be the best way to adapt the Buhlmann algorithm.

Multilevel alters the a-coefficient. It's author, Juergen Bohnert feels this is a safer approach. He also incorporates a seventeen tissue model rather than sixteen which generates much deeper stops. The later versions of XS also incorporate his ZH-L17TS model.

The big talking point is the Gradient Factor method for modifying the a/b coefficients (or m-values) and is incorporated in GUE's Decoplanner, GAP, DDPlan and the latest version of XS. This is based on Erik Baker's article on deep stops which was published in Immersed magazine and is widely available on many diving web sites. Rather than using a fixed conservatism value, it uses two which adapt as the deco progresses. This should be incorporated without any other fudge factors or the schedule becomes infeasibly long.

Other than that, good luck with your DIY deco program!