Basics on using Air Decompression-Tables for Diving

Estimating Data for Dive-Planning

17th September 2002

Minimizing theoretical efforts, the text tries to demonstrate simple procedures for estimating data for dive-planning. The first part shows how to use air decompression-tables; the second part shows how to calculate estimations of data. Due to their easier manageability, the text mostly uses values of physical quantities in SI-units.

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Diving Profiles

Types of Dives

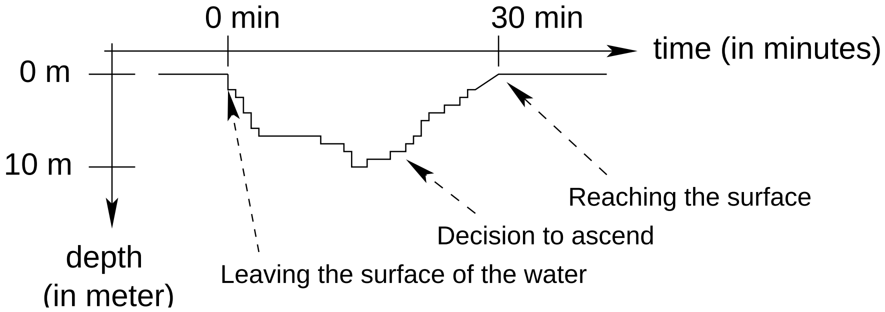
As an overview, discern four types of dives: No-decompression dives, decompression-dives, repetitive dives and high-altitude dives. Some of these types may overlap. Each of these types requires information which may be taken from tables appended to this text.

Usage of Tables

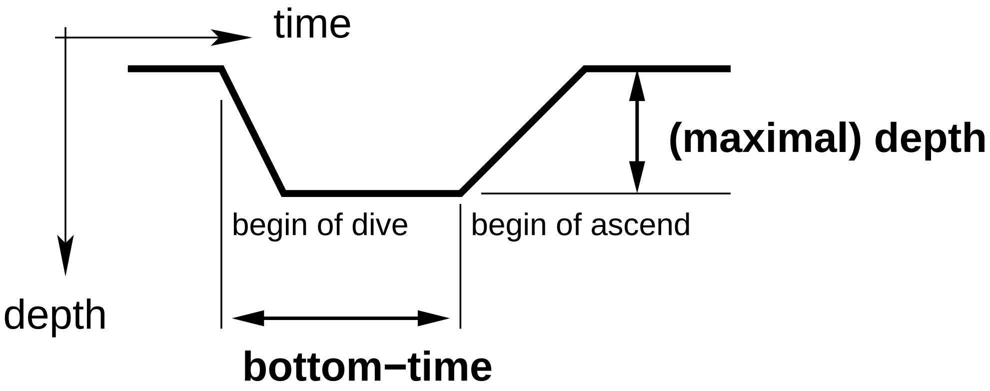
This first part, only acquaints the reader with the usage of the tables. One needn't bother about the finite supply of pressurized air in the tank, which limits the diving-time. Thus, the following assumes that the diver receives pressurized breathing air from the surface of the water, for example by a combination compressor-hose-regulator. This effectively means: Unlimited air supply for the diver; later, in the part about estimating dive-data, examples and calculations consider the case of the limited supply when breathing the air from a tank.

Diving-Profiles and Characterizing Data

A dive may be characterized by some diagram marking depth over time:



These diagrams, also called (diving-)profiles, will be used abbreviated and idealized as follows:



Here, the crucial pieces of data are: The **(maximal) depth** of the dive — to be determined by reading of the depth-gauge. The diving-watch can be used to get a value for time-interval between the beginning of the dive and the beginning of the ascend — the so-called **bottom-time**[1]. The bottom-time is the time which the diver remains under water until deciding to ascend.

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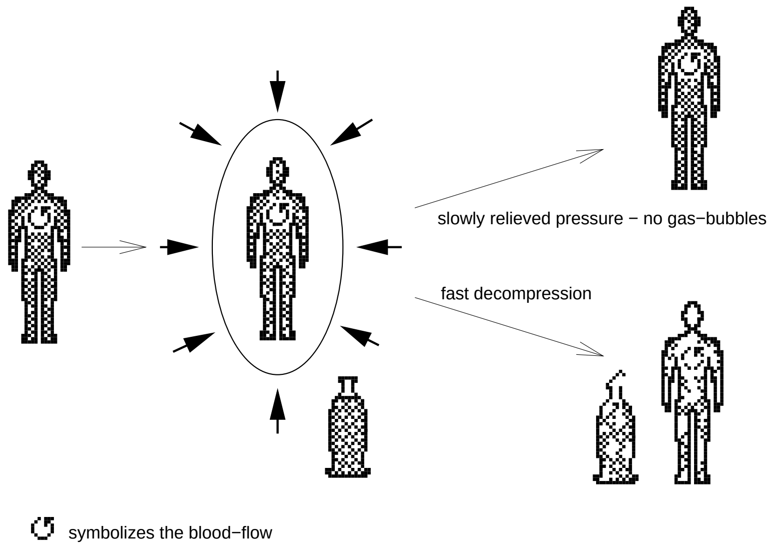
[1] The usefulness of that notion will be indicated on page 5.

Why to avoid a fast ascent when finishing a dive?

Additionally to the atmospheric pressure, a diver has to tolerate the pressure of the water on hers or his body. Divers with scuba equipment breathe pressurized breathing-gas with the surrounding pressure.
This causes the following to happen:
After leaving the surface of the water, the diver breathes air under increased pressure. Diffused through the alveolaric lung-tissue, transported by the blood-stream, additional gas-molecules diffuse into the body-tissue of the diver. Reversing this description tells how the gas-molecules leave the body. If the diver ascends too fast, thus reducing the surrounding pressure too fast, then the additional gas-molecules may not leave the body of the diver fast enough. Within the organs of the diver, the concentration of the gas-molecules may have reached levels that allow the gas to escape the body-tissue only by building gas-bubbles within the body. (As a standard example consider a Cola-bottle: Opening such a bottle causes the, previously pressurized, fluid to encounter a surrounding of much lower (air-) pressure. In the fluid has been dissolved so much gas, that the surplus of solved gas leaves the fluid by building bubbles rather than leaving the fluid by diffusion. The transporting effect of the blood-stream may be idealized by swirling the contents of the bottle.) Gas bubbles inside the organs of a human body hinder them to function properly and may damage them heavily: For symptoms and treatment consult diving-books on Decompression Sickness (DCS).



What is Diffusion?

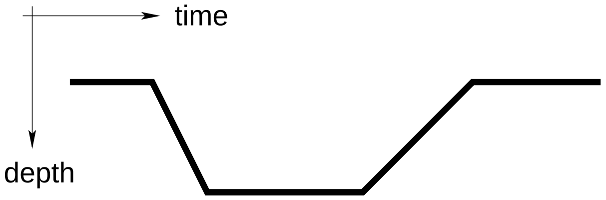
Single particles, (gas-)molecules may enter, move within, and leave fluids (and even massive materials). Usually this may happen only in very small concentrations. The effective movement of such particles/molecules in liquids or solids is called diffusion. The process of diffusion usually is initiated by differences of concentration.

Why may a Diver need Diving-Tables?

The diffusion and concentration of gases within the differing tissues of a diving human are highly interrelated. Therefore the relevant data has to be compiled from laboratory-data, mathematical models and diving-tests. The results have been compiled in tables.

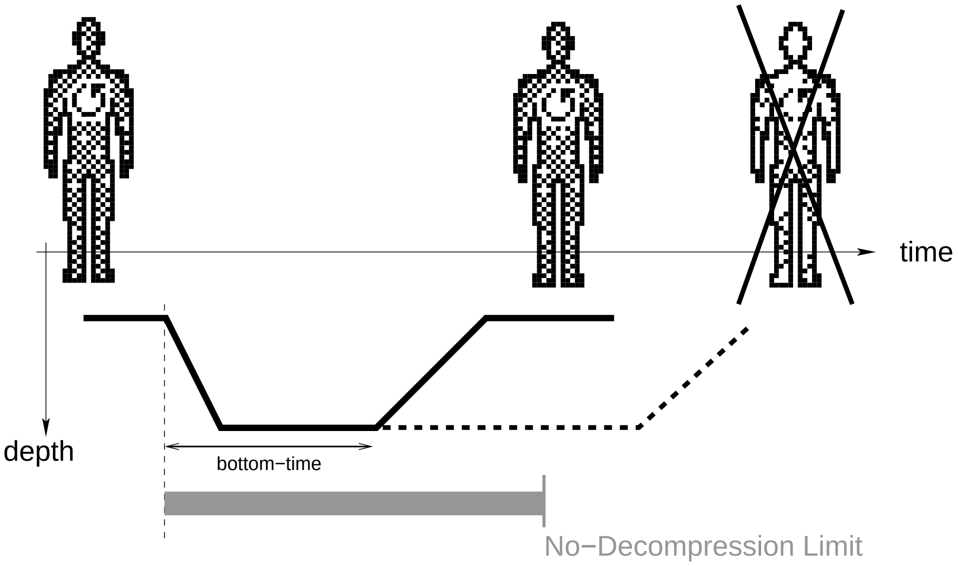
No-Decompression Dives

Sports-divers often do short and shallow dives, there the above-described mechanism of producing bubbles within the body of the diver should not become dangerous. The diver descends, stays a while under water and re-ascends to the surface, as indicated by the following diagram:



How short and how shallow has to be a dive assuring no harmful gas-bubbles within the body of the diver? For each maximal depth exists one special bottom-time up to which the profile above can be dived, without endangering one's health unreasonably: This limiting bottom-time is called No-Decompression Limit. Dives with a bottom-time below the No-Decompression Limit are called **No-Decompression Dives**. Use a given maximal depth to extract the associated No-Decompression Limit from the tables at the end of this text.

Thus, for a given maximal depth, the **No-Decompression Limit** — a time-interval — tells how long a diver can maximally stay under water, from leaving the surface until beginning to ascend directly to the surface.

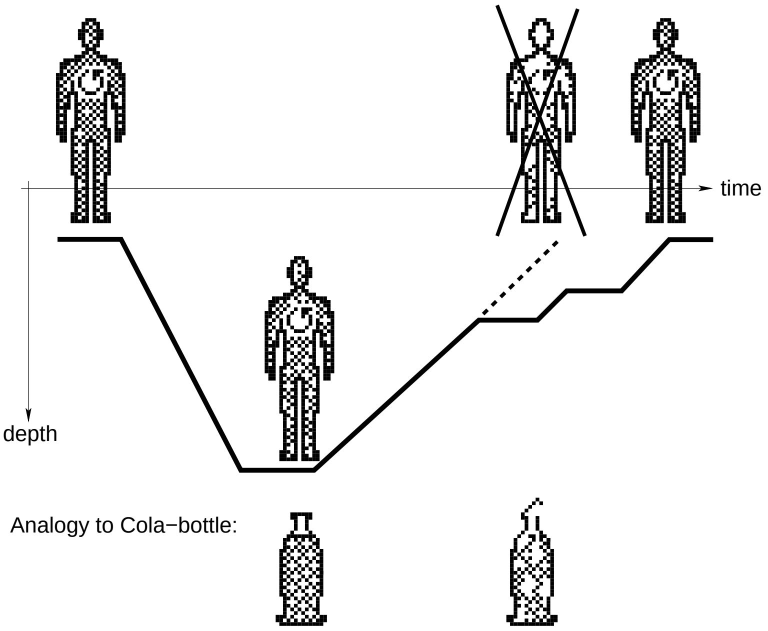


Example:
Dive with maximal depth $25m$. Elapsed time until beginning of ascend: $15min$.
Consider the table at the end of this text.
Therein consider the column 1, Maximal Depth (in meter) $27m$ (Since the table furnishes its values only for selected maximal depths, the given maximal depth of $25m$ of the dive is used to select a larger maximal depth of the table ($27m$), thus overestimating the danger and keeping on the safe side.)
In the part of the table for this value ($27m$) consider the row without any entries in column 3.
Within this row fix the value of column 2: $25min$, the No-Decompression Limit.
Since the elapsed time until beginning of ascend ($15min$) is smaller than the No-Decompression Limit ($25min$), the dive becomes a No-Decompression Dive.

Decompression Dives

Ascending from a long or/and deep dive usually requires also to avoid the dangerous production of gas-bubbles within the body of the diver. How? By ascending so slowly that the surplus of diffusing gas can leave the body over the blood-flow through the lungs. Ascending very slowly usually becomes very difficult. Instead, the ascend may be temporarily interrupted by pausing at prescribed depths.

These pauses or interruptions during the ascend are called **decompression-stops**. Those dives, which require an interrupted ascend to avoid generating health-endangering gas-bubbles within the body of the diver, are called **decompression dives**. The following type of diagram shows such a decompression dive:



For a given bottom-time and a given maximal depth of the dive, tables allow the diver get the decompression-depth and the associated decompression-time for each decompression-stop.

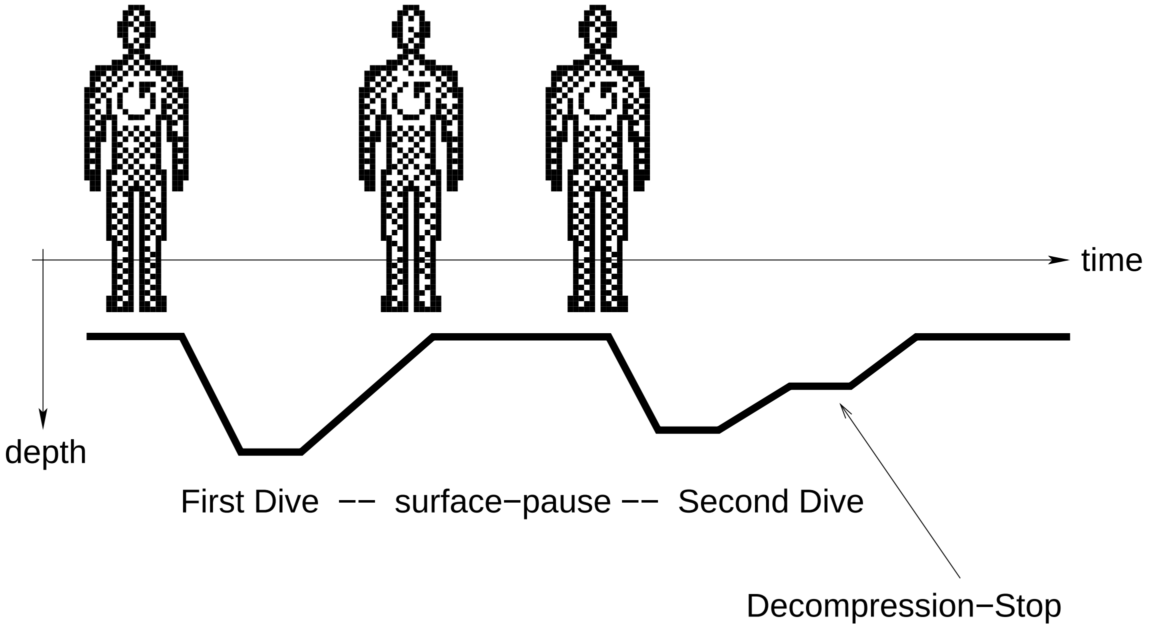
Example:
Dive with maximal depth of $25m$. Until the beginning of the ascend have passed $33min$.
Consider the table at the end of this text.
Follow the column 1, Maximal Depth (in meter) to the part of the table marked by $27m$.
In this part of the table consider the column 2 (bottom-time) and identify the row given by the value $40min$.
This row gives the decompression-profile: During the ascend do stop for five minutes in six meters ($5min$ in $6m$) and do a second stop for five minutes in three meters of depth ($5min$ in $3m$).

(Question: About where can be found the No-Decompression Limit in the diagram above? Answer: In the time-line above BEFORE the beginning of the ascend!) Another question: Why has the notion of the bottom-time been introduced in the way as described on page 2? Reaching the bottom-time the diver knows to finish the dive. The ascending time with decompression-stops has to be determined by consulting the table for a given bottom-time. Characterizing the duration of the dive by the surface-to-surface time would have to include the decompression-stops which depend on the duration of the first part of the dive (the bottom-time).

Repetitive Dives

Even if opened hours ago, a Cola-bottle contains liquid having a slightly sparkling taste. — Hours after a dive, the diver contains a surplus of remaining gas-particles within hers or his body; this remaining, at the water-surface continually diminishing, surplus has to be considered when diving again!

A dive done taking into account the remaining surplus of gas-particles of previous dives within the scuba-diver's body — such a dive is called **repetitive dive**. A repetitive dive characterizes the diagram below:



In the figures of the graphic above, observe the different particle-concentrations within the body of the diver. At those times when the diver leaves the surface, the concentrations differ: The second time can be seen the surplus remaining from the first dive.

Several types of tables quantify the effects of successively pressurizing the human body. Here a simple rule is applied:

Rule for Repetitive Dives Any dive within the last TWELVE (12) hours makes a dive a repetitive dive.

Add the bottom-times, including the intended one for the repetitive dive. Take the maximal depth of all dives including the repetitive dive.

Take the table and read out the dive-data for the repetitive dive using the sum of the bottom-times and the newly established maximal depth.

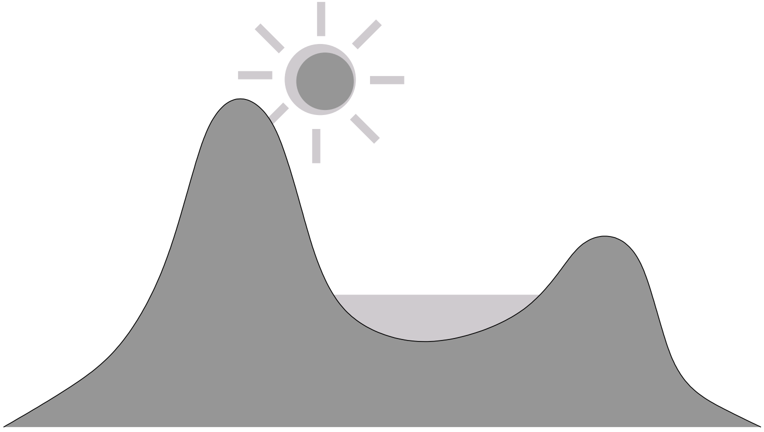
For many cases this rule may prove too conservative, in these cases refrain to the rather optimized tables that support repetitive diving.

Example:
First Dive: (Uses the profile of the No-Decompression example.)
Dive with maximal depth $25m$. Elapsed time until beginning of ascend: $15min$.
Consider the table at the end of this text.
Therein consider the column 1, Maximal Depth (in meter) $27m$.
In the part of the table for this value ($27m$) consider the row without entries in column 3.
Within this row fix the value of column 2: $25min$, the No-Decompression Limit.
Since the elapsed time until beginning of ascend ($15min$) is smaller than the No-Decompression Limit ($25min$), the dive becomes a No-Decompression Dive.
A surface-pause of six hours ($6h$) until the next dive makes that next dive a repetitive dive.
Second Dive:
Dive with maximal depth $25m$. Elapsed time until beginning of ascend: $15min$.
(This is the same profile as the one of the dive six hours ago!) The maximal depths of the two dives remains $25m$. The added bottom-times, twice $15min$ become $30min$:
Reconsider the table for an hypothetical dive of maximal depth $25m$ and a bottom-time of $30min$.
Therein consider the column 1, Maximal Depth (in meter) $27m$; in the part of the table for this value ($27m$) consider the column 2 and identify the row indicating $30min$. This row also suggests to take a decompression-stop of five minutes ($5min$) at the depth of three meters ($3m$).

Notice two things: First, the second, repetitive dive lasts only fifteen minutes ($15min$), but its dive-data is taken for a hypothetical dive of thirty minutes out of the dive-table, thus making a decompression-stop necessary. Second, both dives have an identical profile, nevertheless the second one requires a decompression-stop, due to the remaining surplus of gas-particles within the scuba-diver's body at the beginning of the second dive.

High-Altitude Dives

Diving is also possible in mountain lakes high above the sea-level. In high altitudes the air-pressure of the earth's atmosphere is lower than at sea-level, where the pressure roughly amounts to one bar ($1bar$). In an altitude of about $5000m$, five kilometers (about $15,000ft$), the air-pressure can be measured to be less than half of that at sea-level ($0.5bar$).



Less atmospheric pressure over water is supplemented by about the same pressure increase under water. Thus the relative change of concentration of gas-particles due to the water-pressure is larger than at sea-level. Ascending from a high-altitude dive therefore may require more time to let the surplus of gas-molecules leave the scuba-diver's body. There also exist tables for high-altitude diving.

Three of the more important notions for the following estimation of dive-data are:

(maximal) depth A length, the maximal distance between the water-surface and the diver during a dive. The (maximal) depth also represents one characterizing parameter of the profile of a dive.

bottom-time A time-interval, beginning when leaving the water surface, and ending when the diver begins to ascend towards the surface. The bottom-time describes a part of the profile of a dive.

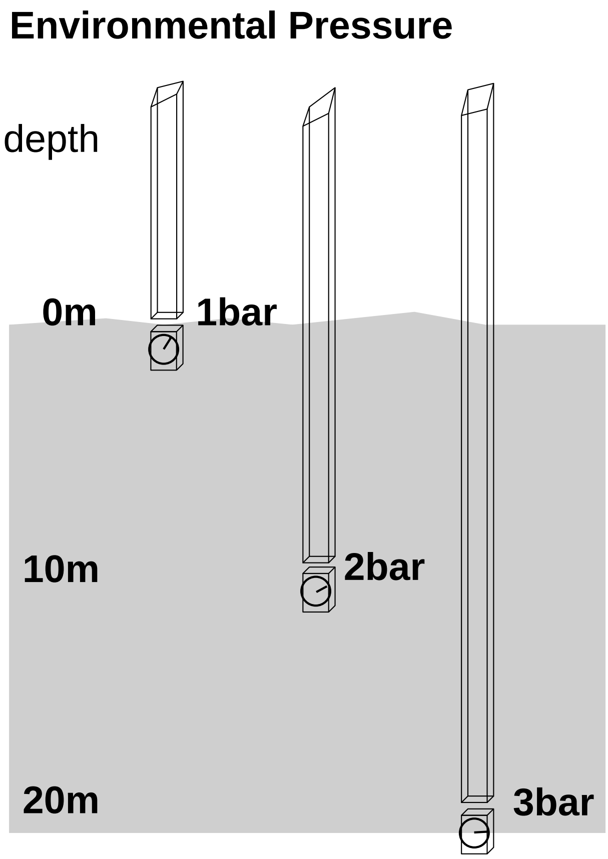
No-Decompression Limit A time-interval, dependent on the value of the maximal depth of a dive. For such a given depth-value, each bottom-time *below* the No-Decompression Limit makes the dive a No-Decompression Dive. A dive with a bottom-time approaching the No-Decompression Limit is on the verge of becoming a decompression dive. The depths and their associated No-Decompression Limits form an envelope in which No-Decompression dives are found.

Physical Properties of Gases

Up to now have been described cases of using the decompression tables with an unlimited supply of breathing-air. But a scuba-diver under water carries only a limited amount of breathable air. Now, for a given amount of breathing-air and for a given maximal diving depth, the maximal bottom-time should be calculated that allows a safe ascend; including decompression-stops. To be able to follow the calculations, the knowledge of some basic physical notions proves to be useful. Nevertheless, the pure mechanics of the calculations can be used without an extensive theoretical background.

Pressure

The gravitational pull of the earth's mass holds the earth together. This gravitational pull also lets the liquid water accumulate in lower areas of the earth's surface forming seas, rivers and lakes. Gaseous material[2], which is specifically lighter than water, rests above the liquid and massive surface thus forming the earth's atmosphere. All these materials experience the gravitational pull. Gases are noticeably compressed giving an atmospheric pressure of about one bar at sea-level. Besides that atmospheric pressure, the water on the surface presses on layer of water below and on the massive parts of the earth. Everyone knows how to move in one bar of gas pressure, breathing, experiencing wind and storm. Under water, has to be added the pressure of the surrounding water. The water pressure increases with depth too, because of the weight the upper layers of water. In physics, the notion "pressure" tells what force acts on what area; one of its units is called "bar". That unit (*bar*) is convenient here, because the atmospheric pressure at sea-level has a value of about one bar.



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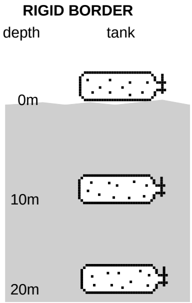
[2] About 78% nitrogen gas (N_2), 21% oxygen gas (O_2), water vapor (H_2O), carbon dioxide (CO_2) and more.

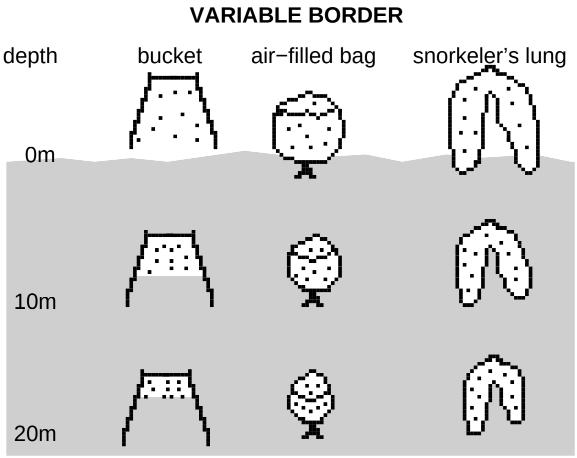
Amount of Gas — Intuitive Definition



The volume is not a useful means to measure the amount of a gas: Inside a scuba-tank may be found only a little volume of compressed air, but that little volume enables the scuba-diver to breathe a long time. Therefore try to clarify the notions: Consider different containers filled with gas and then moved below the water surface:

RIGID AND CLOSED containers can withstand the increased pressure from outside. The material of the container takes the strain induced from difference of pressures from within and from outside; thus within the the rigid and closed container, the pressure remains constant. Rigid and closed containers keep their inside-pressure constant, independent of the pressure outside!

Containers with VARIABLE BORDER, containing an amount of gas, do react differently to a change of environmental pressure: In those containers the gas-pressure equals (or roughly equals) the environmental pressure! The amount of gas is taken to be the same, as indicated by the same number of points in the diagram below. Since gases are much more compressible than liquids, changing the water-pressure changes the volume of the gas inside the container. The deeper the container rests under water, the higher the water-pressure and thus the smaller the volume of the gas.



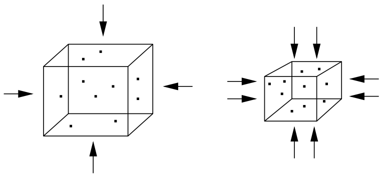
None of the containers in the previously shown two diagrams lets escape any amount of gas (the snorkeler has been asked to hold hers or his breath). Thus the amount of air, the amount of gas has been the same in any depth ($0m$, $10m$ or $20m$).

(Number) An amount of gas can be described by counting the number of gas-particles. (In the diagram on the left are found 10, 8, 10 gas-particles.) For little numbers like multiples of 12 one may use the unit "dozen", for larger numbers like multiples of $6.023 \cdot 10^{23}$ one may use the unit "mol"[3].

(Mass) Or the amount of gas can be described by giving its mass. (In atmospheric pressure at sea-level and in a temperature of about twenty degrees Celsius ($20°C$) one liter of air has been measured to have a mass of $1.3 gram$.)

These two options of describing a given amount of gas may prove un-elegant in the context of diving. Physical quantities which are relatively easy available in diving are **pressure** and **volume**. The pressure is given by pressure-gauges on tanks or the depth-gauge. Volumes are that of the tank or the lung.

Remember that for a given amount of gas (inside the bucket within the diagram above) the larger the pressure, the smaller became the volume. Closer investigation yields: For a given amount of gas the pressure (p) multiplied with the volume (V) is a constant!



$$p \cdot V = constant$$

The doubled amount of gas needs the double volume when the pressure is held constant:

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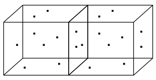
[3] This number can be found in books about natural sciences under the name "AVOGADRO-constant."



$$p \cdot 2 \cdot V = 2 \cdot constant$$

Thus the constant can be seen to be proportional to the amount of gas. So, for a given amount of gas, get its pressure and its volume, multiply both and use the resulting value as a quantifier for the amount of gas:

A given **amount of gas** can be described by the quantity $G := p \cdot V$, where this amount of gas has been once in a state of pressure p and volume V.

Consumption of Air when Breathing under Water

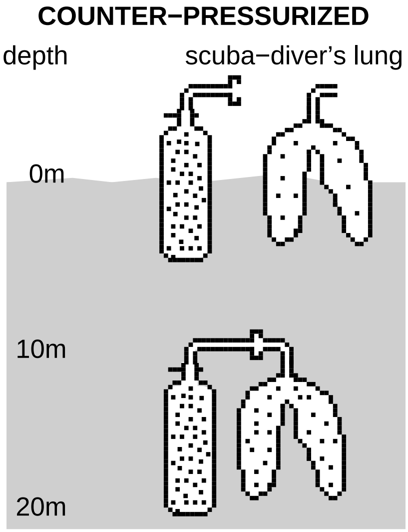
Depending on the scuba-diver's training-condition, the diver breathes a certain *volume* of air per time-interval, the values range from $6 - 7 liters/minute$ at rest to over $100 liters/minute$ under physical- or emotional stress.

Under water, the regulator supplies the breathing-gas with about the pressure of the surrounding water. Thus, apart from breathing, the scuba-diver's lung ideally needs not to work against any outside pressure. And thus the lung is not compressed when scuba-diving, contrary to the case of snorkeling. Under water, a scuba-diver's lung inhales the *same volume* as on the surface of the water!

The lung of a scuba-diver keeps its normal working volume under water, because the regulator supplies the breathing-gas *with* the surrounding pressure. This means, ONE BREATH UNDER WATER HAS THE **SAME VOLUME** AS ONE BREATH ON THE SURFACE OF THE WATER!

The breathing gas is supplied with the pressure of the environment and that pressure is higher than the atmospheric pressure at the water surface. Therefore, under water, one liter of regulator-supplied breathing-gas contains more gas-particles than one liter of breathing-gas at the water surface. This means, ONE BREATH UNDER WATER **CONTAINS MORE GAS-PARTICLES** THAN ONE BREATH ON THE SURFACE OF THE WATER!

So, one breath under water causes more gas-particles to pass the lung than one breath on the surface of the water. This implies that breathing under water needs a larger amount of gas — keeping the same breathing-volume — than breathing on the surface of the water.



For estimating the demand of breathing-air of a scuba-diver under water use the notion "amount of gas" as follows: The breathed volume per minute (vpm) multiplied with the time (t) yields the entire gas-volume breathed within that time-interval: $V_{breathed} = vpm \cdot t$ Multiplied with with the environmental pressure p the breathed volume gives the breathed amount of gas: $G_{breathed} = p \cdot vpm \cdot t$

Quantifying Example: Assume a person to breathe twenty liters per minute ($vpm = 20l/min$) for a time of five minutes ($t = 5min$). Then the breathed volume amounts to a hundred liters ($V_{breathed} = vpm \cdot t = 20l/min \cdot 5min$). Hundred liter of gas have been consumed, this is a *volume* — about the same on the surface of the water as on a given depth under water. Now consider this breathing action in two different surroundings:
CASE 1 (WATER-SURFACE): The *amount* of gas breathed in atmospheric pressure at sea-level ($p = 1bar$) becomes one hundred bar liters: $G_{breathed} = p \cdot vpm \cdot t = 1bar \cdot 20l/min \cdot 5min$
CASE 2 (20 METERS OF DEPTH): The environmental pressure in the depth of twenty meters ($20m$) of water quantifies to three bars ($p = 3bar$), a formula to relate diving depth and environmental pressure will be given in the next section. The *amount* of gas breathed in that depth becomes *three*-hundred bar liters: $G_{breathed} = p \cdot vpm \cdot t = 3bar \cdot 20l \cdot 5$
Thus in twenty meters depth a scuba-diver uses *three-times* the *amount* of gas than at the surface of the water! WHILE BREATHING THE SAME VOLUME PER MINUTE, THE HIGHER ENVIRONMENTAL PRESSURE IN TWENTY METERS UNDER WATER CAUSES THREE TIMES AS MUCH GAS-PARTICLES TO PASS THE SCUBA-DIVER'S LUNGS!

Consider page 18 for estimating a value for the breathing-volume per minute (vpm).

Amount of Gas — Summary and Application

For almost every gas, enclosed within some container, the Boyle-Mariotte law gives the relation between its pressure p and its volume V: $p \cdot V = constant$ The constant is independent of the pressure or the volume of the considered gas in the container, but proportional to the considered amount of gas:

Definition: "amount of gas" $G = p \cdot V$

(The unit for the physical quantity "amount of gas", used here, is "*liter · bar*" or "*bar · liter*" or short "*l · bar*" or "*bar · l*". Usually the dot is omitted.) Besides the intuitive approach, the definition above also can be justified by using the law of the "ideal gas": The Boyle-Mariotte law can be seen as a special case of the more general law of the ideal gas. Any container filled with a gas — the state of the gas may be properly describable by the quadruple (pressure p, volume V, particle-number N, temperature T) — relates that data by the following equation, the law of the ideal gas: $p \cdot V = N \cdot k \cdot T$, the quantity k representing an universal constant[4]. Now can be seen that, for constant temperature, the right side of the equation becomes directly proportional to the number of the particles within the gas! The notion "amount of gas" thus is only useful for environments with relatively constant temperatures, for the intended use in diving this should be usually the case.

One liter of air in atmospheric pressure at sea-level ($1bar$) is the amount of gas which can be described by the value $1barl$. This amount of gas has the mass of about $1.3gram$. The acceleration of this mass can be felt when wind is blowing in ones face.

Tank A tank of a volume of ten liters ($V_T = 10l$), filled with breathing-gas to a pressure of two-hundred bars ($p_T = 200bar$) contains an amount of gas of about two-thousand *bar liter* ($G_T = p_T \cdot V_T = 200bar \cdot 10l = 2000barl$). If that amount of gas is expanded to atmospheric pressure ($p_A = 1bar$), then this amount of gas takes a volume of two-thousand liters $V_A = G_T/p_A = 2000barl/1bar = 2000l$, which is about the volume of a telephone booth, about two cubic-meters.

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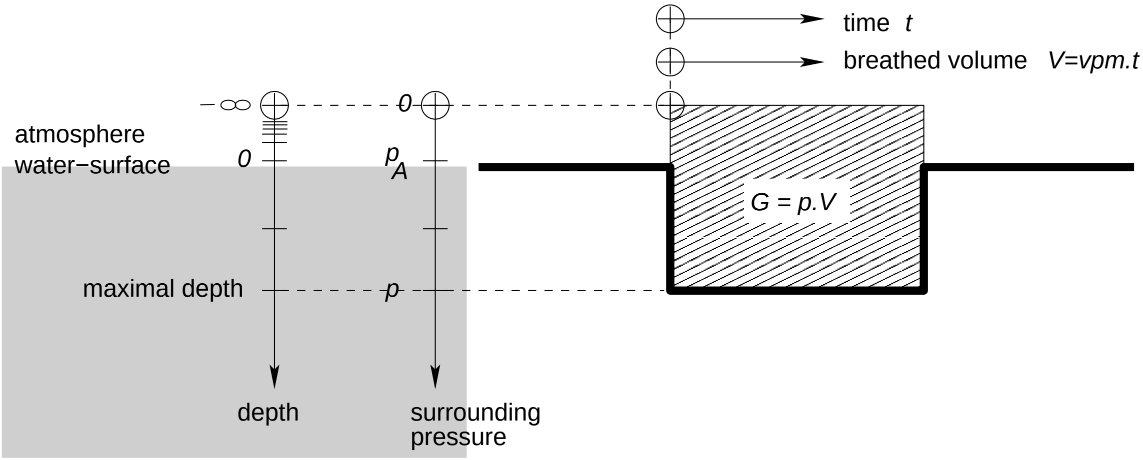
[4] In books on natural sciences, which cover the model of the "ideal gas", the constant k will appear as the BOLTZMANN-constant: $k = 1.381 \cdot 10^{-23} J/K$. The physical properties of real gases can be well described with the law of the "ideal gas", but the law has to be modified within areas of temperature, pressure and volume where real gases change phases, for example when becoming a liquid.

Breathing under water Breathing a certain volume per minute vpm in the time-interval of length t amounts to a breathed volume $V = t \cdot vpm$. The regulator supplies the breathing-gas with the surrounding pressure. If a scuba-diver breathes in a constant depth under water, then the environmental pressure has a constant value. The surrounding pressure p under water at sea-level can be estimated by using the following formula:

$p = 1bar$ (due to atmospheric pressure) + (one bar for each ten meters $10m$ depth of water)

Within an environment of pressure p, during a time-period of length t and a breathing activity with a volume consumption-rate vpm, a scuba-diver uses the following amount of gas:

$$G = p \cdot t \cdot vpm$$



Observe that the vertical scale, denoting a length in the diagram above, has been compressed in the area above the water-surface, so that the pressure-scale becomes linear. Then, the usual depth-over-time diagram for describing diving-profiles can thus be reassessed as a volume-over-pressure diagram! This makes it possible to interpret the calculation of the amount of gas as a process of finding the area in a volume-over-pressure diagram.

Estimating Dive Data

Example for Estimating Data (Rectangle Approximation)

(The boxes $\boxed{}$ within the text below are can be filled by the reader with the appropriate values.)

Consider the following situation: A diver is given a $10l$-tank filled with compressed air at a pressure of $200bar$. The diver plans to dive about $10m$ deep and expects a volume consumption-rate of maximal $30l/min$. How long can the diver remain under water until deciding to ascend?

Tank-Data — Air-Supply What amount of breathing-gas (compressed air) is available?

Volume of tank $V_T = \boxed{}\ l$

Tank-pressure $p_T = \boxed{}\ bar$

Amount of gas in tank $G_T = p_T \cdot V_T = \boxed{}\ barl$
minus a reserve of $500barl$

$G_T = \boxed{}\ barl$ $(1500barl)$

Dive-Data — Air-Demand What amount of breathing-gas is expected to be consumed?

Breathed volume per time-interval $vpm = \boxed{}\ l/min$

planned maximal diving depth $\boxed{}\ m$

gives surrounding pressure $p = \boxed{}\ bar$
(p =atmospheric pressure plus one bar for each ten meters of depth)

bottom-time $t =?$ $G_D = p \cdot t \cdot vpm$

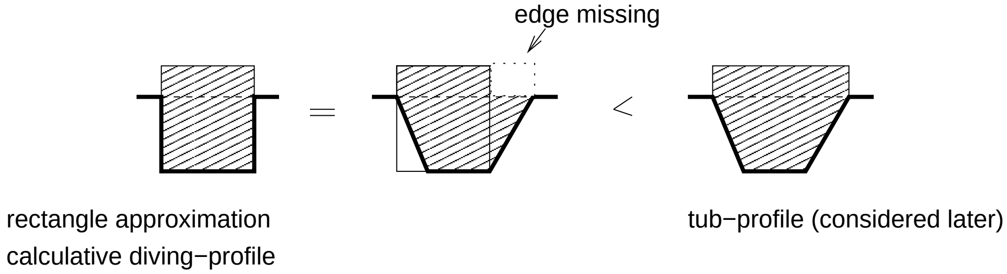
Demand should equal Supply The demanded amount of air should be less or equal the supplied amount, therefore set the demanded and supplied amounts of gas equal and solve the equation for the still unknown time:

$$G_D = G_T$$
$$p \cdot t \cdot vpm = G_T$$
$$t = \frac{G_T}{p \cdot vpm} = \boxed{}\ barl \big/ (\boxed{}\ bar \cdot \boxed{}\ l/min) = \boxed{}\ min$$

(Solution: The bottom-time should count maximal twenty-five minutes ($25min$). This clearly remains below the No-Decompression Limit which can be taken from the decompression-table at the end of the text. See under the part of the table for $12m$, the first row giving the No-Decompression Limit to be $135min$.)

Question: The formula used for the air-demand considered the dive to have a rectangle-profile, as shown in the diagram on page 13. What about descending- and ascending-times and their influence in changing the air-demand? Taking into account descending- and ascending-times actually should make the diving-profile more tub-like.

Answer: Ignore the descending- and ascending-time, because what is spared from the air supply when descending can be used while ascending. More reserves accumulate, because usually the diver does not stay the whole dive at the maximal depth and because of the reserve calculated into the supply above. Thus the use of the bottom-time should cover the additional demand during descend and ascend (another advantage of using the notion “bottom-time”). In other words: By shifting areas, the rectangle-profile can be used to approximate a tub-profile.



Nevertheless this method of calculation may become risky with deep and time-consuming dives, because the diver should try to ascend ($\leq 10 m/min$) more slowly than the diver can controlledly descend ($\leq 48 m/min$). This complication already has been covered by calculating the table-data for a more realistic tub-profile.

Estimating Data for Decompression-Dives

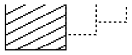
When a person breathes, the inhaled gas-molecules diffuse across the lung-tissue into the blood-stream. The blood-stream transports these gas-molecules to the remaining organs. — A scuba-diver breathes gas supplied from the regulator with the pressure of the surrounding water. The pressure of the breathing-air thus equals that of the environment of the diver (larger than the atmospheric pressure of $1 bar$ at sea-level). Therefore, the concentration of gas-particles within the body of a diver increases with the time stayed under water. If the diver surfaces too fast, then the difference between the gas-concentration/-pressure within the scuba-diver's body and the atmosphere may reach levels in which the diffusion and the blood-stream do not work fast enough to equalize that difference of pressure. This causes the production of gas-bubbles in the body of the diver. Slowing the ascend by inserting decompression-stops hinders the production of dangerous gas-bubbles within the body of the diver, while enabling diffusion and blood-stream to get rid of the surplus of gas-molecules over the lung.

Summary: The limited speed of the blood-flow, especially in capillaries, the limited velocity of the diffusing gas-particles and the limit for dissolving gas-particles within the human body make decompression-stops necessary. Without decompression-stops could occur harmful gas-bubbles within the scuba-diver's body[5].

Remark: As far as possible try to adhere to suggested decompression-stops. This means either to be able to precisely hold ones depth free-floating, which already tends to bind a lot of attention in water without waves; or what is highly advisable, to use the anchor-chain or a rock as a fixing-point. High waves produce an oscillating pressure curve under water, which in extreme cases, can even cause damaging lung-expansion of a scuba-diver!

The Principle of calculating the Air-Demand in Decompression-Dives

The following gives only a coarse demonstration and is not needed in any further calculation. The following intends to give an idea of how to calculate the amount of air needed to do a decompression-dive with two decompression-stops:


Formulate an expression describing the amount of gas needed during a dive with the bottom-time t with a maximal depth of an equivalent environmental pressure p and the volume consumption-rate vpm: $G = p \cdot t \cdot vpm$

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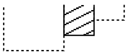
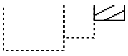
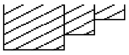
[5] Referred to by diving-books as Decompression Sickness (DCS).


Consider the decompression-stops as mini-dives: $G_{D1} = p_{D1} \cdot t_{D1} \cdot vpm$


Consider the decompression-stops as mini-dives: $G_{D2} = p_{D2} \cdot t_{D2} \cdot vpm$


Add the single amounts of gas up the the entire amount of gas describing the demand for the entire decompression-dive: $G_D = G + G_{D1} + G_{D2}$ with the expressions above inserted: $G_D = p \cdot t \cdot vpm + p_{D1} \cdot t_{D1} \cdot vpm + p_{D2} \cdot t_{D2} \cdot vpm$ and simplified, giving

$$G_D = (p \cdot t + p_{D1} \cdot t_{D1} + p_{D2} \cdot t_{D2}) \cdot vpm$$

For each row of the decompression-table at the end of the text, the factor in parentheses can be calculated from the remaining values given in the decompression-table. This factor is independent from any value related to a concrete dive (vpm, tank-parameters). This value, also called factor g, supplements the decompression-table within a separate column. The factor g stands for an amount of **g**as divided by a volume consumption-rate. The numerical value of g describes the amount of gas demanded for a volume-rate of $1l/min$ to finish the related decompression-dive. The values in the table at the end of the text have been calculated for tub-profiles which yield safer values for larger diving-depths.

Example for Estimating Data with Decompression-stops (Tub-Profile)

Situation: Search-dive in an area of maximal twenty meters ($20m$) of depth, no heavy work, the divers are in a well-trained condition, therefore a volume-consumption-rate of less than twenty liters per minute ($20l/min$) seems realistic. Each diver has been furnished with two ten-liter tanks filled with two-hundred bars ($200bar$) of pressurized air. How long can the search last?

Tank-Data — Air-Supply What amount of breathing-gas is available?

Volume of tank(s) $V_T = \boxed{}\ l$

Tank-pressure $p_T = \boxed{}\ bar$

Amount of gas in tank(s) $G_T = p_T \cdot V_T = \boxed{}\ barl$
minus a reserve of $200barl$

$G_T = \boxed{}\ barl$ ($3800barl$)

Dive-Data — Air-Demand What amount of breathing-gas is expected to be consumed?

Breathed volume per time-interval $vpm = \boxed{}\ l/min$

planned maximal diving depth $\boxed{}\ m$

$G_D = g \cdot vpm$

Demand smaller or equal Supply The demanded amount of air should be less or equal the supplied amount, therefore formulate the inequality-relation and solve it for the unknown g-value:

$$G_D \leq G_T$$
$$g \cdot vpm \leq G_T$$
$$g \leq \frac{G_T}{vpm} = \boxed{}\ barl / \boxed{}\ l/min = \boxed{}\ bar \cdot min \quad (190bar \cdot min)$$

Now, using the planned maximal diving-depth ($20m$), search the related part of the decompression-table ($21m$). Within this part of the table search the smaller value of g which comes closest to the calculated value above. The row thus fixed yields the full diving-profile searched (bottom-time, decompression-stops) together with a guarantee that the air-supply will suffice under the given volume consumption-rate. (Solution: Identify the part of the table for the maximal diving-depth of twenty-one meters ($21m$) under column 1. Choose the second row ($g = 182bar \cdot min$) to get the profile: bottom-time $55min$, decompression-stop $5min$ in $3m$)

Even when considering no-decompression dives, the method above tells this and needs little calculation. Often repetitive dives, even with little bottom-time become easily decompression-dives as could be seen in the example on page 7. Now, how to get an idea of the breath-related volume consumption-rate of a human? See the next section:

Estimating the Volume Consumption-Rate of a Person

Different settings influence the volume of breathing-gas inhaled: The breathing becomes deeper and faster when running. Stress, physical- and mental conditions can be related to different volume consumption-rates when breathing. The same happens under water. But under water the air-supply is limited.

The breathing volume per minute thus varies from person to person and from situation to situation, therefore in this case one can only work with extraordinarily rough approximate values. In diving do use rather a too large value for the volume per minute, which produces a reserve, than under-estimating the consumption and running out of air.

Example for getting a value for a breathing volume per minute under water: Consider the following situation: A diver dives with an eight-liter-tank. The diver tries to keep a steady position in ten meters of depth for five minutes. At the beginning of the time-interval the pressure-gauge of the tank showed hundred and fifty bars, the value at the end showed hundred and ten bars. Can the breathing volume per minute be calculated from that data?

Tank-Data — Air-Supply What amount of breathing-gas was taken from the tank? Subtract the amount of gas at the end of a time-interval from the amount of gas at the beginning of the time-interval to get the amount of gas used up during that time-interval:

Volume of tank	$V_T = \boxed{}\ l$
Tank-pressure at the beginning	$p_{T1} = \boxed{}\ bar$ (of the time-interval)
Tank-pressure at the end	$p_{T2} = \boxed{}\ bar$ (of the time-interval)
Amount of gas supplied by tank (during that time-interval)	$G_{supplied} = G_{T1} - G_{T2} =$ $= p_{T1} \cdot V_T - p_{T2} \cdot V_T = (p_{T1} - p_{T2}) \cdot V_T =$ $= (\boxed{} - \boxed{})bar \cdot \boxed{}\ l = \boxed{}\ barl$ $(320barl)$

Dive-Data — Air-Demand What amount of breathing-gas has been consumed by the diver during that time-interval? Formulate the expression that contains the breathed volume per minute:

Length of time-interval	$t = \boxed{}\ min$
Diving depth $\boxed{}\ m$	during that time-interval
gives surrounding pressure	$p = \boxed{}\ bar$
(p =atmospheric pressure plus one bar	for each ten meters of depth)
Breathed volume per minute	$vpm = ?$ $G_{demanded} = p \cdot t \cdot vpm$

Demand should equal Supply Equalize the demanded amount of air to the supplied amount and solve for the unknown value giving the volume per minute breathing-flow:

$$\begin{aligned} G_{demanded} &= G_{supplied} \\ p \cdot t \cdot vpm &= G_{supplied} \\ vpm &= \frac{G_{supplied}}{p \cdot t} = \boxed{}\ barl \Big/ (\boxed{}\ bar \cdot \boxed{}\ min) = \boxed{}\ l/min \quad (32l/min) \end{aligned}$$

Factors that increase the volume consumption-rate of a diver are

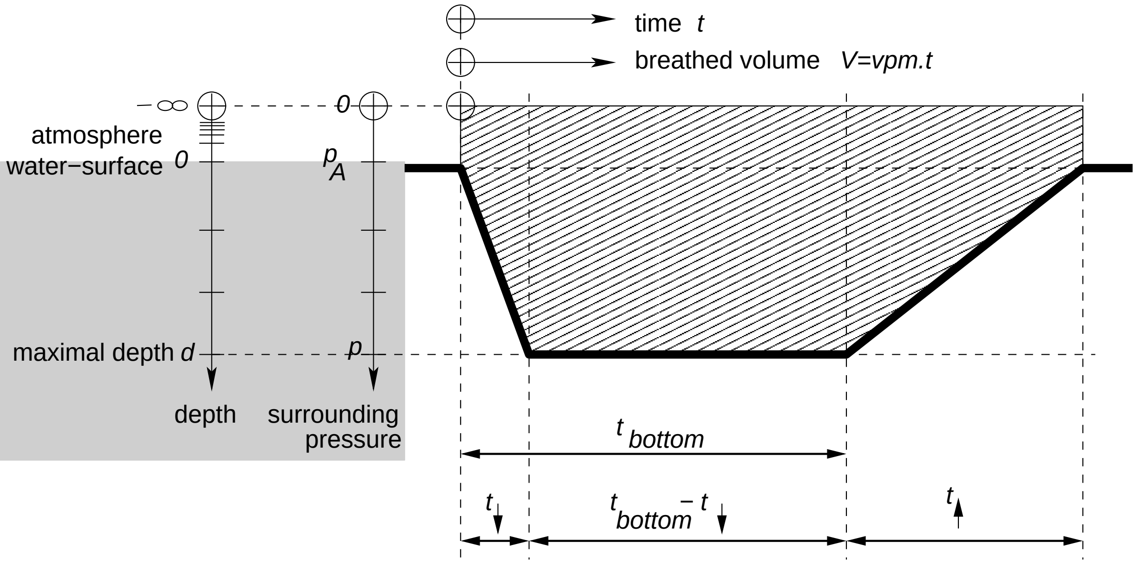
- irritation, excitement (new dive-partner, new dive-location, new gear)
- physical activity, physical stress (fin movement following a compass-setting)
- chill, hypothermia

Common values for breathing volumes per minute are: $10 - 20l/min$ for trained divers resting comfortably in the water; $20 - 35l/min$ and more for beginners. Under the circumstances mentioned above, these values can double, triple or even quadruple. Women usually have a lower air consumption-rate than men.

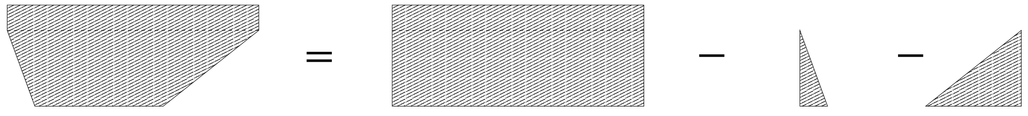
The quality of the estimations depends highly on being able to predict one's consumptions of volume during the dive. Especially when planning decompression-dives be aware of the option to begin ascending prematurely before reaching the No-Decompression Limit! Sometimes even harmless incidents that haven't been predicted may be taken as a reason to make the dive shorter than intended. Generally a surplus of *filled* and *available* tanks *with regulators* may have a reassuring effect. The calculative procedures above and below ONLY describe freedom and limits of diving which are feasible by simple mathematical models of the physical effects. The variety of social effects often constitutes another source of hopefully manageable risks.

Calculations with a Tub-Profile

As shown on page 15, the rectangle approximation of a diving profile tends to underestimate the demand of breathing-air. This becomes especially problematic when considering profiles where the descend happens faster than the ascend and when diving to relative large depths. Therefore the values for the normed demand of breathing-gas g have been calculated for a tub-profile as described below:



The relevant parameters are: t_{bottom} the bottom-time; $t_{\downarrow}$ duration of descend; $t_{\uparrow}$ duration of ascend; p_A atmospheric pressure, usually $1bar$; p the environmental pressure at the maximal depth of the dive; $v_{\downarrow}$ velocity of the descend (here the suggested maximal value of $48m/min$); $v_{\uparrow}$ velocity of the ascend (here the suggested maximal value of $10m/min$); and finally d the maximal depth of the dive. If the diagram above is considered as a pressure-over-volume graph ($G = p \cdot V$), then the area with the line-pattern represents the amount of gas used. The value of that area can be calculated in different ways by dividing it into rectangles and triangles; below has been calculated the area of the circumscribing rectangle minus the two white triangles giving the amount of gas needed:

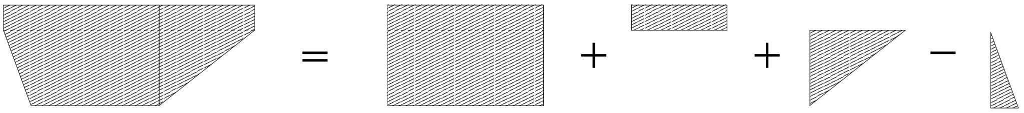


$$G_{tub} = \underbrace{p \cdot vpm \cdot (t_{bottom} + t_{\uparrow})}_{cirumscribing\, rectangle} - \underbrace{\frac{(p - p_A) \cdot vpm \cdot t_{\downarrow}}{2}}_{minus\, left\, triangle} - \underbrace{\frac{(p - p_A) \cdot vpm \cdot t_{\uparrow}}{2}}_{minus\, right\, triangle}$$

And simplified by gathering same factors:

$$G_{tub}/vpm = p \cdot (t_{bottom} + t_{\uparrow}) - (p - p_A) \cdot \frac{t_{\uparrow} + t_{\downarrow}}{2}$$

Reassembling summands and factors or adding areas of rectangles and triangles differently also yields:



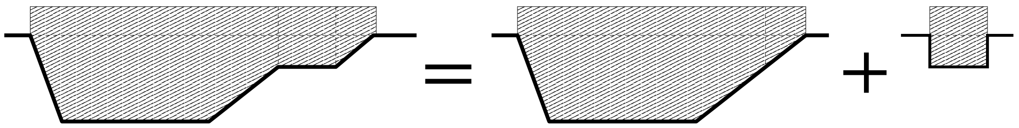
$$G_{tub}/vpm = p \cdot t_{bottom} + p_A \cdot t_{\uparrow} + (p - p_A) \cdot \frac{t_{\uparrow} - t_{\downarrow}}{2}$$

Compare the result above to the result of the rectangle approximation $G_{rect}/vpm = p \cdot t_{bottom}$: Since all the factors are non-negative — ascending usually takes more time than descending ($t_{\uparrow} \geq t_{\downarrow}$) and $p \geq p_A$— the rectangle approximation clearly underestimates the demand, the underestimation even persists in the case $t_{\uparrow} = t_{\downarrow}$! The deeper the dive and the larger the difference between ascending- and descending-time, the more significant becomes the deviation from the rectangle-approximation. The above states in formulas what already could be assessed form the previous graphics on page 15.

Now make the descending and ascending diving-velocities part of the formula: Therefore observe the relation $t_{\downarrow} \cdot v_{\downarrow} = d = t_{\uparrow} \cdot v_{\uparrow}$, this permits to eliminate the descending- and ascending-times from the formula:

$$G_{tub}/vpm = p \cdot (t_{bottom} + \frac{d}{v_{\uparrow}}) - \frac{1}{2}(p - p_A) \cdot d \cdot (\frac{1}{v_{\downarrow}} + \frac{1}{v_{\uparrow}})$$

And finally, the amount of gas consumed during decompression-stops can be easily integrated by simply adding results from properly chosen rectangle profiles:



Equality and addition with respect to the amount of gas

The values within the column g in the table have been calculated according to this method.

Decompression Table

1		2	3								4
maximal depth	g	bottom-time	decompression-stops (minutes)								total ascend-time
(meter)	(bar min)	(minutes)	24m	21m	18m	15m	12m	9m	6m	3m	(minutes)
No guarantees for any feature or use of this table											
10	no limit										1
12	301	135									1
	374	165								5	5
	447	195								10	10
	519	225								15	15
	592	255								20	20
	765	330								25	25
	904	390								30	30
	1508	660								35	35
		over 660								40	40
15	216	85									1
	273	105								5	5
	317	120								10	10
	361	135								15	15
	393	145								20	20
	437	160								25	25
	471	170							5	25	30
	527	190							5	30	35
	674	240							10	40	50
	1008	360							30	40	70
	1242	450							35	40	75
		over 450							35	45	80
18	172	60									1
	207	70								5	5
	243	80							5	5	10
	277	90							5	10	15
	312	100							5	15	20
	347	110							5	20	25
	382	120							5	25	30
	416	130							5	30	35
	452	140							10	30	40
	494	150							10	40	50
	530	160							15	40	55
	594	180							20	40	60
	676	200						5	30	40	75
	855	255						10	35	45	90
	1079	325						20	40	45	105
	1586	496						35	40	45	120
		over 495						35	40	50	125

1		2	3								4
maximal depth	g	bottom-time	decompression-stops (minutes)								total ascend-time
(meter)	(bar min)	(minutes)	24m	21m	18m	15m	12m	9m	6m	3m	(minutes)
21	128	40									2
	182	55								5	5
	205	60							5	5	10
	243	70							5	10	15
	265	75							5	15	20
	303	85							5	20	25
	325	90							5	25	30
	350	95						5	5	25	35
	394	105						5	5	35	45
	456	120						5	10	40	55
	525	135						5	20	45	70
	588	150						5	30	45	80
	651	165						10	30	50	90
	715	180						15	35	50	100
	836	210						25	40	50	115
	950	240					5	30	40	50	125
24	107	30									2
	148	40								5	5
	190	50							5	5	10
	214	55							5	10	15
	237	60							5	15	20
	278	70							5	20	25
	302	75							5	25	30
	335	80						5	5	30	40
	384	90						5	10	35	50
	457	105						5	20	40	65
	542	120					5	5	30	45	85
	635	140					5	10	35	50	100
	761	160					10	30	40	50	130
27	98	25									2
	124	30								5	5
	169	40							5	5	10
	194	45							5	10	15
	219	50							5	15	20
	244	55							5	20	25
	272	60						5	5	20	30
	297	65						5	5	25	35
	331	70						5	10	30	45
	357	75						5	15	30	50
	390	80						5	20	35	60
	442	90						5	25	40	70
	494	100						5	30	45	80
	569	110					5	15	35	45	100
	623	120					5	20	35	50	110
	709	135				5	5	25	40	50	125
	794	150				5	10	35	40	50	140

1		2	3								4
maximal depth	g	bottom-time	decompression-stops (minutes)								total ascend-time
(meter)	(bar min)	(minutes)	24m	21m	18m	15m	12m	9m	6m	3m	(minutes)
30	87	20									2
	113	25								5	5
	142	30							5	5	10
	168	35							5	10	15
	195	40							5	15	20
	222	45							5	20	25
	251	50						5	5	20	30
	278	55						5	5	25	35
	312	60						5	10	30	45
	375	70						5	20	35	60
	402	75						5	20	40	65
	449	80					5	5	30	40	80
	515	90					5	15	30	45	95
	609	105					5	25	35	50	115
	710	120				5	10	30	40	50	135
33	81	17									2
	100	20								5	5
	130	25							5	5	10
	158	30							5	10	15
	186	35							5	15	20
	215	40							5	20	25
	246	45						5	5	20	30
	282	50						5	10	25	40
	318	55						5	15	30	50
	354	60						5	20	35	60
	382	65						5	20	40	65
	431	70					5	10	20	45	80
	470	75					5	15	25	45	90
	510	80					5	20	30	45	100
	581	90				5	5	20	40	45	115
	652	100				5	10	25	40	50	130
	735	110				5	20	30	45	50	150
	822	120			5	5	25	40	45	50	170

1		2	3								4
maximal depth	g	bottom-time	decompression-stops (minutes)								total ascend-time
(meter)	(bar min)	(minutes)	24m	21m	18m	15m	12m	9m	6m	3m	(minutes)
36	73	14									2
	108	20								5	5
	139	25							5	5	10
	175	30							5	15	20
	205	35							5	20	25
	244	40						5	5	25	35
	275	45						5	10	25	40
	313	50						5	15	30	50
	361	55					5	5	20	35	65
	409	60					5	10	25	40	80
	489	70					5	20	30	45	100
	532	75				5	5	20	35	45	110
	576	80				5	10	25	35	45	120
	657	90				5	15	30	40	50	140
	746	100			5	5	20	35	45	50	160
	838	110			5	15	25	40	45	50	180
	919	120			5	20	35	40	45	50	195
39	64	11									3
	90	15								5	5
	123	20							5	5	10
	154	25							5	10	15
	192	30							5	20	25
	216	35							5	20	25
	265	40						5	10	25	40
	315	45					5	5	15	30	55
	354	50					5	5	20	35	65
	403	55					5	10	25	40	80
	452	60					5	15	30	45	95
	541	70				5	10	20	30	50	115
	602	75				5	15	25	40	50	135
	656	80				5	20	30	45	50	150
	749	90			5	5	25	40	45	50	170
	850	100		5	5	15	30	40	45	50	190
	948	110		5	10	25	30	45	45	50	210
	1046	120		5	15	30	40	45	45	50	230

1		2	3								4
maximal depth	g	bottom-time	decompression-stops (minutes)								total ascend-time
(meter)	(bar min)	(minutes)	24m	21m	18m	15m	12m	9m	6m	3m	(minutes)
42	58	9									3
	70	10								5	5
	104	15							5	5	10
	137	20							5	10	15
	169	25							5	15	20
	212	30						5	5	20	30
	252	35						5	10	25	40
	304	40					5	5	15	30	55
	346	45					5	10	15	35	65
	396	50					5	15	20	40	80
	450	55				5	5	15	25	45	95
	501	60				5	5	20	35	45	110
	556	65				5	10	25	40	45	125
	610	70				5	15	30	40	50	140
	678	75			5	5	20	35	45	50	160
	717	80			5	10	20	35	45	50	165
	776	85			5	15	25	40	45	50	180
	879	95		5	5	20	35	40	45	50	200
	981	105		5	15	25	35	45	45	50	220
	1083	115		5	20	35	40	45	45	50	240
45	57	8									3
	74	10								5	5
	110	15							5	5	10
	151	20							5	15	20
	194	25						5	5	20	30
	237	30						5	10	25	40
	282	35					5	5	10	30	50
	333	40					5	10	15	35	65
	385	45					5	15	20	40	80
	440	50				5	5	15	25	45	95
	503	55				5	10	20	30	50	115
	559	60				5	15	25	35	50	130
	618	65			5	5	15	30	40	50	145
	678	70			5	10	20	30	45	50	160
	738	75			5	15	25	35	45	50	175
	815	80		5	5	20	30	40	45	50	195
	880	85		5	10	25	35	40	45	50	210
	955	90		5	15	30	40	45	45	50	230

1		2	3								4
maximal depth	g	bottom-time	decompression-stops (minutes)								total ascend-time
(meter)	(bar min)	(minutes)	24m	21m	18m	15m	12m	9m	6m	3m	(minutes)
48	87	10							5	5	10
	122	15							5	10	15
	168	20						5	5	15	25
	211	25						5	10	20	35
	258	30					5	5	10	25	45
	311	35					5	10	15	30	60
	362	40					5	10	20	40	75
	427	45				5	5	15	25	45	95
	485	50				5	10	20	30	45	110
	551	55				5	15	25	40	45	130
	612	60			5	5	20	25	40	50	145
	681	65			5	10	20	35	45	50	165
	743	70			5	15	25	40	45	50	180
	811	75		5	5	20	30	40	45	50	195
	878	80		5	10	25	35	40	45	50	210
	954	85		5	15	30	40	45	45	50	230
50	90	10							5	5	10
	126	15							5	10	15
	173	20						5	5	15	25
	224	25						5	10	25	40
	280	30					5	5	15	30	55
	334	35					5	10	20	35	70
	394	40				5	5	15	25	35	85
	459	45				5	10	20	30	40	105
	528	50			5	5	10	25	35	45	125
	593	55			5	5	15	30	40	50	145
	664	60			5	10	20	35	45	50	165
	734	65		5	5	15	25	35	45	50	180
	798	70		5	10	15	30	40	45	50	195
	876	75		5	15	20	35	45	45	50	215
	953	80	5	5	20	25	40	45	40	50	230
54	96	10							5	5	10
	144	15						5	5	10	20
	191	20						5	10	15	30
	247	25					5	5	10	25	45
	310	30					5	10	15	35	65
	379	35				5	5	15	20	40	85
	446	40				5	10	20	25	45	105
	518	45			5	5	10	25	35	45	125
	585	50			5	5	15	30	40	50	145
	658	55			5	10	20	35	45	50	165
	739	60		5	5	15	25	40	45	50	185
	809	65		5	10	20	30	40	45	50	200
	888	70		5	15	25	35	45	45	50	220
	975	75	5	5	20	30	40	45	45	50	240

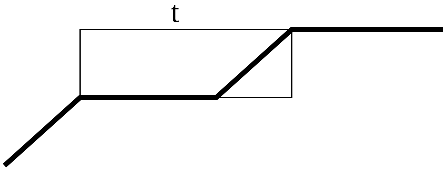
1		2	3								4
maximal depth	g	bottom-time	decompression-stops (minutes)								total ascend-time
(meter)	(bar min)	(minutes)	24m	21m	18m	15m	12m	9m	6m	3m	(minutes)
57	100	10							5	5	10
	157	15						5	5	15	25
	205	20						5	10	20	35
	264	25					5	5	15	25	50
	341	30				5	5	10	20	35	75
	413	35				5	5	15	30	45	100
	490	40			5	5	10	20	35	45	120
	559	45			5	5	15	25	40	50	140
	633	50			5	10	20	30	45	50	160
	716	55		5	5	15	25	35	45	50	180
	797	60		5	10	20	30	40	45	50	200
	880	65	5	5	10	25	35	45	45	50	220
	967	70	5	10	15	30	40	45	45	50	240
60	112	10							5	10	15
	163	15						5	5	15	25
	224	20					5	5	10	20	40
	276	25					5	10	15	20	50
	368	30				5	5	15	20	40	85
	446	35				5	10	20	30	45	110
	532	40			5	5	15	25	40	45	135
	615	45			5	10	20	30	45	50	160
	699	50		5	5	15	25	35	45	50	180
	781	55		5	10	20	30	40	45	50	200
	867	60	5	5	10	25	35	45	45	50	220
	955	65	5	10	15	30	40	45	45	50	240

The amount of breathing gas G needed for the entire profile can be calculated by multiplying the expected mean breathing volume per minute vpm with the associated factor g: $G = g \cdot vpm$. The value g has been calculated for a tub-profile with a velocity of descend of $48m/min$ and a velocity of ascent of $10m/min$ (these are maximal values, if possible try to stay below those values). The atmospheric pressure is taken to have a value of $1.01325bar$.

The table has been taken from the German GUV 10.7 (Edition of July 1985, a copy taken from the VBG39) with permission. The table has been generated by the Schifffahrts-Medizinisches-Institut der Marine in Kiel (Germany). A newer version of a table can be found in the BGV C23 (former VGB39) Edition of the 1st of January 2001.

(stress) The table has been designed for divers who do medium work. If HARD WORK has been done under water, then use the NEXT ROW with the more extended decompression-stops. Remember that a planned diving-profile represents the envelope of the technically possible, within this envelope ideally the diver *alone* decides according to the personal condition about the actual duration of the dive.

(ascending-time) The ascending to decompression-depths has been included into the timing of the decompression-stops.



(calm decompression-stops) If possible, avoid too much movements during decompression-stops.

(anticipation) Strive to be prepared for the potentially unexpected, especially for accidents, have proper gear readied (list of decompression-chambers in the vicinity, mobile-phone, filled oxygen-tanks, . . .), consult books or use training facilities.

The decompression table also covers high-altitude dives: Either use a barometer to get a value of the atmospheric pressure p_H at the diving-site. OR, if the height h over the sea-level is known *in meter*, try to estimate that barometric pressure with the formula

$$p_H = 1 - h/meter \cdot 0.0001225$$

(Giving about $0.4bar$ for $5000meter$ of altitude above sea-level). Observe that from $p_A \geq p_H$ (the atmospheric pressure at sea-level has a larger value than in outer levels of the atmosphere) follows $\frac{p_A}{p_H} \geq 1$ and $\frac{p_H}{p_A} \leq 1$!

If the actual maximal depth of the high-altitude dive is given by the value d then search the values of the calculative diving profile in the table for a LARGER depth of the value $d_{table} = d \cdot \frac{p_A}{p_H}$.

But use SHALLOWer decompression-depths calculated from the decompression depths in the table as follows: $d^{deco} = d^{deco}_{table} \cdot \frac{p_H}{p_A}$

CAUTION: Depth-gauges may not work properly due to the lower atmospheric pressure and due to the fact that fresh water is less dense that salt-water!

The NO-Calculation! Approach by Mr. Klaus Ritter

Mr. Klaus Ritter from Waiblingen in Germany suggested the following procedure which eliminates ANY calculation and therefore should be most reliable in a diving-situation outside: A diver used to dive with the same tank-configuration and who can well estimate the volume-consumption-rate, may generate tables which immediately give the relevant g-value. Thus, just a *two*-table lookup yields the complete extremal diving-profile:

TANK-VOLUME $10l$

g-entries in $bar \cdot min$	volume-consumption-rate in l/min						
TANK-PRESSURE in bar	18 l/min	20 l/min	22 l/min	24 l/min	25 l/min	27 l/min	30 l/min
220 bar	100	90	82	75	72	67	60
210 bar	94	85	77	71	68	63	57
200 bar	89	80	73	67	64	59	53
190 bar	83	75	68	63	60	56	50
180 bar	78	70	64	58	56	52	47
170 bar	72	65	59	54	52	48	43
160 bar	67	60	55	50	48	44	40
150 bar	61	55	50	46	44	41	37
140 bar	56	50	45	42	40	37	33
130 bar	50	45	41	38	36	33	30
120 bar	44	40	36	33	32	30	27
110 bar	39	35	32	29	28	26	23
100 bar	33	30	27	25	24	22	20
90 bar	28	25	23	21	20	19	17
80 bar	22	20	18	17	16	15	13

TANK-VOLUME $12l$

g-entries in $bar \cdot min$	volume-consumption-rate in l/min						
TANK-PRESSURE in bar	18 l/min	20 l/min	22 l/min	24 l/min	25 l/min	27 l/min	30 l/min
220 bar	124	112	102	93	90	83	75
210 bar	118	106	96	88	85	79	71
200 bar	111	100	91	83	80	74	67
190 bar	104	94	85	78	75	70	63
180 bar	98	88	80	73	70	65	59
170 bar	91	82	75	68	66	61	55
160 bar	84	76	69	63	61	56	51
150 bar	78	70	64	58	56	52	47
140 bar	71	64	58	53	51	47	43
130 bar	64	58	53	48	46	43	39
120 bar	58	52	47	43	42	39	35
110 bar	51	46	42	38	37	34	31
100 bar	44	40	36	33	32	30	27
90 bar	38	34	31	28	27	25	23
80 bar	31	28	25	23	22	21	19
70 bar	24	22	20	18	18	16	15

TANK-VOLUME $15l$							
g-entries in $bar \cdot min$	volume-consumption-rate in l/min						
TANK-PRESSURE in bar	18 l/min	20 l/min	22 l/min	24 l/min	25 l/min	27 l/min	30 l/min
220 bar	161	145	132	121	116	107	97
210 bar	153	138	125	115	110	102	92
200 bar	144	130	118	108	104	96	87
190 bar	136	123	111	102	98	91	82
180 bar	128	115	105	96	92	85	77
170 bar	119	108	98	90	86	80	72
160 bar	111	100	91	83	80	74	67
150 bar	103	93	84	77	74	69	62
140 bar	94	85	77	71	68	63	57
130 bar	86	78	70	65	62	57	52
120 bar	78	70	64	58	56	52	47
110 bar	69	63	57	52	50	46	42
100 bar	61	55	50	46	44	41	37
90 bar	53	48	43	40	38	35	32
80 bar	44	40	36	33	32	30	27
70 bar	36	33	30	27	26	24	22
60 bar	28	25	23	21	20	19	17

References

For some more related information also about further literature see:

`http://www.diversresource.com`

`http://www.naui.org`

`http://diverlink.com/training/lht/divetablecomparison.htm`

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