Blood Gas Analysis, Oxygen Transport, Electrolytes Balance, Glucose and Bilirubin Determination

A Short Survey on Measured, Calculated and Special Parameters
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INTRODUCTION

The accurate determination of the acid base status as well as the status of oxygenation is an extremely important procedure in medicine. Instrumentation Laboratory, the undisputed leader in the field of Blood Gas Analysis and CO-Oximetry, was one of the first companies to develop a software program for its 1600 series, BGE and 1306 Blood Gas analyzers allowing an interface with its CO-Oximeters IL 482 and IL 682 and providing useful informations on various aspects of pathophysiology. Now, with the introduction of the new generation of analyzers - the “Synthesis” - which incorporate a revolutionary CO-OX technology, Instrumentation Laboratory, once again, hits the target for the third millennium’s users: the availability of systems capable of measuring blood gas, electrolytes, glucose, bilirubin and CO-Oximetry parameters starting from a single whole blood sample.

In addition:
A further example of the IL’s strong commitment toward innovative proposals is offered by the GEM family of analyzers. The extremely simplified operation and the use of the “maintenance-free” GEM cartridges allows the user to carry out the determination of important blood gas, electrolyte and hematocrit parameters directly “at the patient’s bed side” thus, reducing significatively the lead time between diagnosis and therapy.

This booklet is a revision of our first edition issued in 1994. Changes have been made to reflect our new generation of analyzers. We wish to offer to all of our end users (both in the central laboratory and in the point of care units) a brief update on the most significant parameters involved in the Acid Base Status, Oxygen Transportation, Electrolytes Balance and Glucose and Bilirubin Determination as they are understood at Instrumentation Laboratory.

The following pages contain:
• A brief explanation of all the parameters that are currently furnished by the IL systems (their definitions, significances and reference ranges as reported in bibliography).
• The way that they are obtained, including the formulas for the calculations.
• Further details on the meaning of the “special parameters”
ABBREVIATION AND SYMBOLS

INSTRUMENTS

Synthesis 35: Blood Gas/Electrolytes/Glucose/Hematocrit/CO-OX/Bilirubin analyzer
Synthesis 30: Blood Gas/Electrolytes/Glucose/Hematocrit analyzer
Synthesis 25: Blood Gas/Electrolytes/Hematocrit/CO-OX/Bilirubin analyzer
Synthesis 20: Blood Gas/Electrolytes/Hematocrit analyzer
Synthesis 15: Blood Gas/CO-OX/Bilirubin analyzer
Synthesis 10: Blood Gas analyzer
1660: Blood Gas/Electrolytes/Glucose/Hematocrit analyzer
1630/40/50: Blood Gas/Electrolytes/Hematocrit analyzer
1610/20: Blood Gas analyzer
BGE: Blood Gas/Electrolytes/Hematocrit analyzer (model 1400)
1306: Blood Gas analyzer (model 1306)
482/682: IL CO-Oximeters (models 482 and 682)
237: IL Tonometer (model 237)
GEM Premier Plus
GEM Premier: Blood Gas/Electrolytes/Hematocrit analyzer

GAS

O₂: oxygen
CO₂: carbon dioxide
CO: carbon monoxide
BP: barometric pressure
N₂: nitrogen
VP: partial pressure of water vapour
%FIO₂: fraction of inspired oxygen in percent

GENERAL PREFIXES

p: partial pressure(tension) F: fractional concentration in dry gas phase
s: saturation of hemoglobin D: gradient
C: content TC: temperature correction
V: ventilation R: respiratory quotient
Q: cardiac output

With reference to the lungs (capital letters)
A: alveolar gas E: mean expired gas
D: dead space gas T: tidal gas

With reference to the blood (lower case letters)
a: arterial \( \overline{v} \): mixed venous
c: capillary

Examples
paO₂: partial pressure of oxygen in arterial blood
svO₂: mixed venous oxygen saturation
CcO₂: oxygen total content in capillary blood
pACO₂: partial pressure of alveolar carbon dioxide
**Synthesis 10**
IL 1610/20 (or 1306)
**pH/Blood Gas analyzers**
Acid base balance.

**Synthesis 20/30**
IL 1630/40/50/60 (or BGE)
**pH/Blood Gas/Electrolytes/ Glucose/Hematocrit analyzers**
Acid base balance, electrolytes, glucose and hematocrit

**IL 482 - IL 682**
**CO-OXIMETERS**
Hemoglobin and oxygenation parameters.

**OXYGEN TRANSPORT**
- \( pO_2 \): oxygen partial pressure
- \( pAO_2 \): oxygen partial pressure in alveolar gas
- \( paeO_2/pAO_2 \): ratio between oxygen tension in arterial blood and oxygen tension in alveolar gas *
- \( paeO_2/FIO_2 \): ratio between oxygen tension in arterial blood and fraction of inspired oxygen *
- \( Hb \): hemoglobin concentration
- \( %O_2 Hb \): % of oxyhemoglobin
- \( %COHb \): % of carboxyhemoglobin
- \( %MetHb \): % of methemoglobin
- \( %Rhb \): % of reduced hemoglobin
- \( O_2ct \): oxygen content
- \( O_2cap \): oxygen capacity
- \( %sO_2c \): calculated oxygen saturation
- \( %sO_2m \): measured oxygen saturation
- \( A-AO_2 \): alveolar-arterial oxygen gradient
- \( Rl \): respiratory index
- \( a-vDO_2 \): arterial-mixed venous oxygen gradient
- \( CoO_2 \): capillary oxygen content
- \( GiO_2 \): arterial oxygen content
- \( CvO_2 \): mixed venous oxygen content
- \( Qsp/Qt \): physiologic shunt
- \( PO_2 \): \( pO_2 \) at 50 of %O_2 Hb
- \( Hct \): hematocrit (not available in Synthesis 10/15, 1610/20 and 1306)

**ACID BASE STATUS**
- \( pH/cH \): hydrogen ion activity
- \( pCO_2 \): carbon dioxide partial pressure
- \( HCO_3^- \): bicarbonate ion concentration
- \( SBC \): standard bicarbonate
- \( BEb \): base excess blood
- \( BEecf \): base excess extra cellular fluid
- \( TCO_2 \): carbon dioxide content

**ELECTROLYTES BALANCE/GLUCOSE/ BILIRUBIN DETERMINATION**
(not available in Synthesis 10/15, 1610/20 and 1306)
- \( Na^+ \): sodium
- \( K^+ \): potassium
- \( Cl^- \): chloride (not available in GEM family)
- \( Ca^{++} \): ionized calcium
- \( Ca^{++}(pH7.4) \): ionized calcium normalized at pH 7.4
- \( Anion Gap \): (only with Cl channel)
- Glucose (available only in 1660 and Synthesis 30/35)
- Total Bilirubin (available only in Synthesis 15/25/35)
- Osmolality (available only in 1660 and Synthesis 30/35)

**IL Synthesis 15**
**pH/Blood Gas/CO-OX/Bili analyzer**
Acid base balance, bilirubin, hemoglobin and oxygenation parameters.

**IL Synthesis 25**
**pH/Blood Gas/Electrolytes/Hematocrit/ CO-OX/Bili analyzer**
Acid base balance, electrolytes, hematocrit, bilirubin, hemoglobin and oxygenation parameters.

**IL Synthesis 35**
**pH/Blood Gas/Electrolytes/GLucose/ Hematocrit/CO-OX/Bili analyzer**
Acid base balance, electrolytes, glucose, hematocrit, bilirubin, hemoglobin and oxygenation parameters.
This chapter defines all the parameters which are available from IL Blood Gas/ Blood Gas-Electrolytes/Blood Gas-Electrolytes-Glucose and Blood Gas-Electrolytes-Glucose-CO-Ox-Bili instruments (first group), by the single CO-Oximeters (second group) and by some models of the two groups when interfaced.

For each parameter, a notation explains if the parameter is a direct measurement or a value calculated by the instruments.

**MEASURED PARAMETERS**

**pH/cH: hydrogen ion activity** (measured by all the Synthesis and 1600 models, GEM family, BGE and 1306)

The concept of pH was introduced in order to simplify the expression of extremely low hydrogen ion activity.

pH is defined as the negative logarithm of hydrogen ion activity: \(-\log[H^+]\). The notation cH mostly used by Scandinavian authors, has the advantage of being linear and not logarithmic, cH measures hydrogen ion activity in nanomoles/liter.

The relationship between cH and pH is: \(cH = 10^{9pH}\).

**pCO2: carbon dioxide partial pressure** (measured by all the Synthesis and 1600 models, GEM family, BGE and 1306)

**pO2: oxygen partial pressure** (measured by all the Synthesis and 1600 models, GEM family, BGE and 1306)

The partial pressure (tension) of a compound in solution is defined as the partial pressure of that compound in a gas phase in equilibrium with the solution. For a mixture of gases, the law of partial pressure (Dalton’s law) states that each gas exerts the same pressure as it would exert if it alone occupied the whole volume: the pressure each gas exerts is called its partial pressure.

For example, in atmospheric air, which is the mixture of oxygen, nitrogen, carbon dioxide and water vapor, the total (barometric) pressure is given by \(BP = pO2 + pN2 + pCO2 + pH2O\).

The two parameters are the measurements of the partial pressure of O2 and CO2 physically dissolved in blood samples.

**%O2Hb: oxyhemoglobin percentage** (measured by Synthesis 15/25/35, IL CO-OX 482 and 682)

Represents the percentage of hemoglobin combined with oxygen in the total amount of hemoglobin.

**%COHb: carboxyhemoglobin percentage** (measured by Synthesis 15/25/35, IL CO-OX 482 and 682)

The percentage of hemoglobin combined with carbon monoxide in the total amount of hemoglobin.

Hemoglobin affinity for carbon monoxide is about 210 times greater than for oxygen.

City dwellers that are non-smokers, typically have carboxyhemoglobin values of less than three percent. In heavy smokers, as much as ten percent or more of the blood hemoglobin may be combined with carbon monoxide.
%MetHb: methemoglobin percentage (measured by Synthesis 15/25/35, IL CO-OX 482 and 682)
The percentage of hemoglobin in which the reduced iron (Fe++) is oxydized to Fe+++ versus the total amount of hemoglobin. Methemoglobin is an “inactive” hemoglobin (in respect to gas exchange and transport) which is not able to combine reversibly with oxygen.

%RHb (or %HHb): reduced hemoglobin percentage (measured by Synthesis 15/25/35, IL CO-OX 482 and 682)
Represents the percentage of hemoglobin not bound with oxygen but still available for binding. It is an early indicator of cyanosis.

Na+: sodium (measured by Synthesis 20/25/30/35, 1630/40/50/60, GEM family and BGE)
The most abundantly represented cation of plasma. Sodium ion constitutes the foremost agent in the maintenance of osmolality and body fluid volumes. It also plays a major role in neuromuscolar excitability.

K+: potassium (measured by Synthesis 20/25/30/35, 1630/40/50/60, GEM family and BGE)
The maintenance of costant K+ concentrations in various body compart-
ments is an essential requisite for correct neuromuscolar excitability. Predominantly an intracellular cation, K+ ions level in the extracellular fluids is associated with muscular contraction and the heart rate.

Ca++: ionized calcium (measured by Synthesis 20/25/30/35, 1640, GEM family and BGE)
Ionized calcium is the physiologically active fraction of total calcium. Calcium ions are involved in a number of enzymatic processes, blood coagulation, cell growth, membrane transport mechanism. nervous impulse conduction, neuromuscolar transmission, muscular contraction and relaxation.

Cl-: chloride (measured by Synthesis 20/25/30/35, 1650 and BGE)
Chloride is the main extracellular anion. Along with Na+, it accounts for the best part of osmotic activity of the plasma and contributes materially to the maintenance of electroneutrality.

Glu: glucose (measured by Synthesis 30/35 and 1660)
Glucose concentration in blood (glycemia) is an important diagnostic test for diabetes and to monitor its derived complications (retinopathy, renal failure, neuropathy and atherosclerosis). Glucose is necessary to check the efficacy of the insulin therapy and also contributes to the regulation of the fluids’ osmolality.

T. Bili: total bilirubin (measured by Synthesis 15/25/35)
Total bilirubin determination in blood is an important test for liver diseases. In particular, in neonatal and pediatric intensive care units, this parameter is used to monitor different hemolytic diseases in the newborn (example: erythroblastosis and obstructive or physiological jaundice).

Hct: hematocrit (measured by Synthesis 20/25/30/35, 1630/40/50/60, GEM family and BGE)
Defined as the ratio of the volume occupied by the red cells to the volume of whole blood, hematocrit is indirectly measured by measuring the electrical conductivity of the blood sample and correcting for the amount of sodium ions present.
CALCULATED PARAMETERS

**HCO₃⁻**: bicarbonate ion concentration (calculated by all the Synthesis and 1600 models, GEM family, BGE and 1306)
Actual bicarbonate ion concentration is calculated from the measured values of pH and pCO₂ in whole blood samples using the Henderson-Hasselbalch equation:

\[
\text{pH} = \text{pK} + \log \frac{[\text{HCO}_3^-]}{0.03 \times \text{pCO}_2}
\]

**SBC**: standard bicarbonate (calculated by all the Synthesis and 1600 models, BGE and 1306)
Is the calculation of the plasma bicarbonate ion concentration after the blood has been equilibrated to a pCO₂ of 40 mmHg.
It is traditionally considered the reflection of a metabolic acid-base change.

**BEb**: base excess blood (calculated by all the Synthesis and 1600 models, GEM family, BGE and 1306)
Is defined as the number of milliequivalent per liter of bicarbonate above (or below) the normal base buffer level.
The calculation of this parameter is an attempt to quantify the patient’s total base excess (or deficit) and is performed from the measurements of pH, p,aCO₂ and hemoglobin.

**BEecf**: base excess extra cellular fluid (calculated by all the Synthesis and 1600 models, BGE and 1306)
This parameter differs from the base excess blood because it represents the entire body extracellular fluid of which blood constitutes only 37%.

**TCO₂**: carbon dioxide content (calculated by all the Synthesis and 1600 models, GEM family, BGE and 1306)
Is calculated as the sum of the bicarbonate ions concentration plus the carbon dioxide physically dissolved in plasma. The resulting value represents the sum of the metabolic and respiratory buffer factors.

**%sO₂C**: calculated oxygen saturation (calculated by all the Synthesis and 1600 models, GEM family, BGE and 1306)
Blood is in contact with oxygen at a certain partial pressure (pO₂) and becomes saturated to a certain level (sO₂).
The actual relationship between saturation and partial pressure is defined by a sigmoid curve known as oxyhemoglobin dissociation curve.
The parameter sO₂C is calculated assuming that the oxyhemoglobin dissociation curve is not shifted (P₅₀ normal).
If the actual curve of the patient under examination is not ideal, for example in presence of COHb in the sample, the %sO₂C will be affected by error

**A-aDO₂**: alveolar-arterial oxygen gradient (calculated by all the Synthesis and 1600 models, BGE and 1306)
Calculated if the FIO₂ value is entered.
For a given FIO₂, a certain pO₂ level should be found in the alveoli (according to the ideal alveolar gas equation) and another, lower by a physiologic range, in the arteries.
This parameter represents an indication of the efficiency of the exchange of oxygen between the lungs and the arterial blood.
\( pAO_2 \): partial pressure of oxygen in alveolar gas (calculated by all the Synthesis models when the fraction of inspired oxygen is entered)

\( paO_2 \)/\( pAO_2 \): ratio between oxygen tension in blood and oxygen tension in alveolar gas (calculated by all the Synthesis model when the fraction of inspired oxygen is entered)

This parameter represents an indication of the efficiency of the exchange of oxygen between the lungs and the arterial blood.

\( RI \): respiratory index (calculated by all the Synthesis and 1600 models, BGE and 1306)

Calculated if the FIO2 value is entered.

The index of the ratio between the alveolar-arterial oxygen gradient and the arterial oxygen partial pressure.

\( paO_2 \)/\( FIO_2 \): ratio between oxygen tension in blood and fraction of inspired oxygen (calculated by all the Synthesis models if the FIO2 value is entered and the A-aDO2 /\( pAO_2 \) /RI block is enabled in the VDU/Printout format screen).

This parameter represents an indication, in the arterial blood, of the efficiency of the gradient of administered oxygen (FIO2) for patients in hypoxemia and oxygen therapy.

\( Hb \): total hemoglobin (calculated by Synthesis 15/25/35, CO-OX 482 and 682)

Total hemoglobin is calculated by summing up the measured hemoglobin derivatives: oxyhemoglobin (O2Hb), carboxyhemoglobin (COHb), methemoglobin (MetHb) and reduced hemoglobin (RHb).

\( O_{2ct} \): oxygen content (calculated by Synthesis 15/25/35, CO-OX 482 and 682)

The calculation of the oxygen content is based on the total Hb and \( %O_2Hb \).

The value is different from the total oxygen content because it does not consider physically dissolved oxygen but only the oxygen combined with hemoglobin.

\( O_{2cap} \): oxygen capacity (calculated by Synthesis 15/25/35, CO-OX 482 and 682)

This calculation is based on Hb, \( %O_2Hb \) and \( %RHb \).

It gives the maximum amount of oxygen that can be carried by the blood sample being analyzed. Physically dissolved oxygen is not considered.

\( %sO_2m \): measured oxygen saturation (calculated by Synthesis 15/25/35, CO-OX 482 and 682)

Represents the percentage of hemoglobin combined with oxygen in the amount of hemoglobin available for oxygenation (oxyhemoglobin + reduced hemoglobin).

\( Ca^{++} \) (pH 7.4): ionized calcium normalized at pH 7.4 (calculated by Synthesis 20/25/30/35, 1640, GEM family and BGE)

The concentration of ionized calcium is dependant on the pH value of the sample. If alterations of pH values occur during the pre-analytical phase (for example during serum/plasma preparation) these are corrected for the calculation of this parameter. Of course the quantity that better reflects the in-vivo ionized calcium activity is the measured value obtained on fresh and anaerobically sampled whole blood specimen. Particular care should also be employed in the choice and in the amount of anticoagulant.
**Anion Gap** (calculated by Synthesis 20/25/30/35, 1650 and BGE)

Is defined as the difference between the greater concentration of anions compared to cations in the plasma electrolytes quota that is not usually assayed. The anion gap represents the predominance of proteins, organic acids, phosphate and sulphate as opposed to magnesium and calcium.

**Osmolality** (calculated by Synthesis 30/35 and 1660 when Na+, Glu and BUN concentrations are determined or inserted)

Osmolality expresses the concentrations of some active particles (sodium, glucose, urea) per given mass of biological fluid. It affects the blood osmotic pressure which regulates the fluid movements across the membranes from the vascular compartment to the interstitial space and vice versa.

**SPECIAL PARAMETERS**

**CcO₂** : *capillary oxygen content* (calculated by Synthesis 15/25/35 and by all 1600 models, BGE and 1306 when interfaced to CO-OX 482 and 682)

The total oxygen content in pulmonary capillary blood. It is the sum of hemoglobin bound plus physically dissolved oxygen in pulmonary capillary blood.

**CaO₂** : *arterial oxygen content* (calculated by Synthesis 15/25/35 and by all 1600 models, BGE and 1306 when interfaced to CO-OX 482 and 682)

The total oxygen content of arterial blood. It is the sum of hemoglobin bound plus physically dissolved oxygen in arterial blood.

**CvO₂** : *mixed venous oxygen content* (calculated by Synthesis 15/25/35 and by all 1600 models, BGE and 1306 when interfaced to CO-OX 482 and 682)

The total oxygen content of mixed venous blood. It is the sum of hemoglobin bound plus physically dissolved oxygen in mixed-venous blood.

**Qₕ/Qₜ** : *physiologic shunt* (calculated by Synthesis 15/25/35 and by all 1600 models, BGE and 1306 when interfaced to CO-OX 482 and 682)

Is the portion of cardiac output that does not exchange with alveolar air. In general term, this can be described as a fluidic “short circuit” in the circulatory system. This occurs when venous circulation passes by unnatural means into arterial circulation, without being reoxygenated. Valuable in evaluation of various cardiopulmonary diseases.

**a-vDO₂** : *arterial-mixed venous oxygen gradient* (calculated by Synthesis 15/25/35 and by all 1600 models, BGE and 1306 when interfaced to CO-OX 482 and 682)

Is the difference in oxygen content between arterial and mixed venous blood. At the site of tissues, blood releases oxygen and takes on carbon dioxide. The amount of oxygen released depends on blood flow and oxygen consumption. This parameter can be used in determining the cardiac output (Fick method).

**PₕO₂** : *pO₂ at 50% oxyhemoglobin* (calculated by Synthesis 15/25/35 and by all 1600 models, BGE and 1306 when interfaced to CO-OX 482 and 682)

This value indicates the partial pressure of oxygen at which hemoglobin is 50% bound with oxygen. Any deviation indicates a shift of the oxyhemoglobin dissociation curve either to the left or to the right.
FRACTION OF INSPIRED OXYGEN

Definition
The fraction of inspired oxygen (FIO₂) can be defined as the measurable percentage of oxygen administered to the patient. For example, if in a tidal volume of 500 mL the oxygen content is 250 mL, the % FIO₂ value is 50%. In other words, we are not interested in knowing how the gases are distributed over the whole tracheobronchial system and the pulmonary parenchyma; what we want to know is that 50% of the total gas inspired is represented by oxygen. This give us a straightforward term which is practical and coherent and can easily be applied to any oxygen therapy method.

ALVEOLAR-ARTERIAL OXYGEN GRADIENT

Definition
Inspired ambient air (O₂ = 20.9, corresponding approximately to a pO₂ = 150 mmHg and a pCO₂ of approximately zero) is mixed in the lungs with gases which have already undergone exchanges with blood, thus having a low oxygen and high carbon dioxide content. This mixture of gases is known as the alveolar air. Some alveoli receive less air due to their anatomical position and therefore contain a lower percentage of oxygen. Blood in contact with these alveoli is oxygenated to a lesser extent. In some illnesses, such as pneumonia, some alveoli are obstructed and blood in contact with them cannot be oxygenated. Blood, oxygenated in the lungs, is contaminated by veins, which unload waste directly into the arterial circulation. This contamination also diminishes the quantity of oxygen in the arterial blood. Phatological conditions, such as lung tumors or cardiac illnesses, increase this contamination.

Fig. 1 - Variations of oxygen tension in man
The A-aDO2 parameter measures the difference in oxygen tension between the alveolar air pAO2 (calculated) and the arterial blood paO2 (measured) giving a general indication of the efficiency of the oxygen exchange process in the alveolar-capillary unit.

**Significance**
This measurement represents the grade of respiratory efficiency in newborn infants as well as in adults:
- Detects dangerous respiratory syndromes.
- Represents an indication of the grade of cardio-pulmonary shunt if the patient is administered high percentages of oxygen.

**Calculation**
The A-aDO2 is calculated from the formula:

\[
A-aDO_2 = pAO_2 \text{(TC)} - paO_2 \text{(TC)}
\]

where:

\[
pAO_2 \text{(TC)} = FIO_2 \times BP \text{(TC)} - paCO_2 \text{(TC)} \times (FIO_2 + \frac{1 - FIO_2}{R})
\]

\[
FIO_2 = \frac{\%FIO_2}{100}
\]

\[
BP \text{(TC)} = BP - VP
\]

\[
VP = 0.4 + \text{antilog} \ (0.0244T + 0.7659)
\]

\[R = \text{respiratory quotient} = 0.8.\]

Ratio between volumes of CO2 produced and volumes of O2 consumed.

**Reference ranges**
7 to 13 mmHg: for young adults (25-30 years of age) breathing ambient air
35 to 45 mmHg: for young adults (25-30 years of age) breathing 100% oxygen.
A-aDO2 rises with age due to the normal decrease of oxygen tension in the arteries.

**RESPIRATORY INDEX**

**Definition**
The respiratory index is the ratio between the alveolar-arterial oxygen gradient and the arterial oxygen partial pressure.

**Significance**
- Represents an index in the evaluation of the reduction of respiratory functions.
- Clinically used as an indicator of the difficulties of oxygen exchange.
- Evaluates the extent of ARDS (Adult Respiratory Distress Syndrome) disorders.
- Can detects ARDS problems more accurately than the alveolar-arterial oxygen gradient.

**Calculation**

\[
RI = \frac{A-aDO_2}{paO_2}
\]

**Reference range**
Less than 0.15.
Definition
Another parameter which is particularly valuable for the evaluation of oxygenation is the “oxygen content” which completes the information supplied by the oxygen tension and by the saturation values. In patients with low hemoglobin levels, the oxygen tension and the saturation values may indicate sufficient oxygenation but, if there is little hemoglobin available for the transport of oxygen, there may be, in reality, a deficiency of oxygen in tissues. Recent studies using intact red blood cells and hemolized blood have shown that the oxygen transport capacity of one gram of hemoglobin is about 1.39 mL. The total oxygen content represents the sum of the oxygen bound to the hemoglobin plus the one physically dissolved in the plasma.

Fig. 2 - Oxygen content. Total oxygen content is shown, along with the portion attached to hemoglobin and the portion dissolved in plasma. When hemoglobin is not fully saturated, a small increase in pO₂ will result in a large increase in oxygen content. When hemoglobin is maximally saturated, a large increase in pO₂ is accompanied by a small increase in oxygen content.
Calculation

1) Hemoglobin content [gr/100 mL] x 1.39 [Vol/gr] x \(\frac{\%O_2Hb}{100}\) = oxygen attached to hemoglobin [Vol/100 mL].

2) \(pO_2\) [mmHg] x 0.003 [Vol/100 mL x mmHg](*) = oxygen physically dissolved in the plasma [Vol/100 mL].

3) Stages 1+2 = total oxygen content [Vol/100 mL].

Example 1: arterial blood
Hb = 15 gr/100 mL; \(pO_2\) = 100 mmHg; \(\%O_2Hb\) = 99
1) 15 x 1.39 x 0.99 = 20.64 Vol/100 mL
2) 100 x 0.003 = 0.30 Vol/100 mL
3) 20.94 Vol/100 mL = \(CaO_2\)

Example 2: mixed venous blood
Hb = 15 gr/100 mL; \(pO_2\) = 40 mmHg; \(\%O_2Hb\) = 70
1) 15 x 1.39 x 0.70 = 14.60 Vol/100 mL
2) 40 x 0.003 = 0.12 Vol/100 mL
3) 14.72 Vol/100 mL = \(CvO_2\)

(*) 0.003 is derived from the Bunsen solubility coefficient for oxygen: in 100 mL of blood for each millimeter of mercury of oxygen partial pressure, 0.003 mL of oxygen are physically dissolved.

Clinical causes of abnormality of the \(pO_2\) content

a) Hypoxemia which corresponds to a reduction of the hemoglobin saturation (and therefore a reduction of oxygen content)

b) Hypercapnia, acidemia, hyperthermia which cause the shift of the hemoglobin dissociation curve towards the right. In these conditions the hemoglobin has a saturation value lower than normal at any arterial oxygen tension.

c) Hypoxemia and acidemia in combination can cause the oxygen content value to drop to critically low levels. In any case where acidemia and hypoxemia co-exist one should assume that there is hypoxia of the tissues.

d) Anemia obviously causes a drop in the oxygen content as the quantity of hemoglobin per 100 milliliters of blood is lower.

Other than by these factors, the oxygen content of blood can be lowered by other analogous factors such as methemoglobin and intoxication by carbon monoxide.

Reference ranges
\(CaO_2\): Male 17.6 to 24.3 Vol% - Female 15.7 to 21.6 Vol%
\(CvO_2\): Male 7.5 to 17.5 Vol% - Female 6.7 to 15.6 Vol%
**ARTERIAL-MIXED VENOUS OXYGEN GRADIENT**

**Definition**
When the oxygenated blood from the lungs comes in contact with tissues, it releases oxygen and takes up carbon dioxide. The quantity of oxygen donated depends upon two factors:
- the speed of blood flow
- the consumption by tissues.
The first of these factors can be detected from the cardiac output. The second depends upon the metabolic rate of the patient. The a-vDO$_2$ is the measurement of the difference in oxygen between the arterial blood and the mixed venous blood, in other words the amount of oxygen donated to tissues. This parameter is neither an indicator of the basic metabolism nor an index of the cardiac output. It is an aspecific indication even if, in some cases (completely relaxed patients with a constant metabolic rate), it can be related to the cardiac output.

**Calculation**
a-vDO$_2$ = CaO$_2$ - CvO$_2$

**Reference range**
a-vDO$_2$ = 4.5-6 Vol%

**PHYSIOLOGIC SHUNT**

**Definition**
Venous blood is carried to the lungs for reoxygenation. However a small amount of this blood passes through the bronchial, pleural and thebesian veins and becomes mixed with arterial oxygenated blood. The “pollution action” is known as the “anatomical shunt”. In addition, some of the venous blood passes through lung capillaries in contact with alveoli which are not ventilated, giving rise to the “capillary shunt”.

*Fig. 3 - Concept of physiologic shunt (see text for explanation).*
A third cause of shunt is usually called “venous admixture”. This occurs in an alveolar-capillary unit that has either a poorly ventilated alveolus or an excessive rate of blood flow. Blood leaving this unit has a lower oxygen content than blood leaving a normal alveolar-capillary unit. The sum of these three shunts is known as the “physiologic shunt” (Fig. 3). This parameter is of great importance, because an increase in shunt is one of the primary causes of hypoxemia and an indication of many pathological pulmonary condition. An increase in shunt can, however, be compensated by an increase in cardiac output.

**Calculation**
The percentage of shunt is expressed by the ratio $Q_{sp}/Q_t$ where $Q_{sp}$ is the sum of the absolute shunt and shunt effect and $Q_t$ is the total cardiac output. The formula for the calculation is the classic physiologic shunt equation:

$$\frac{Q_{sp}}{Q_t} = \frac{CcO_2 - CaO_2}{CcO_2 - CvO_2}$$

where:

- $CaO_2$ = Arterial oxygen content = \((1.39 \times Hb \times \frac{\%O_2aHb}{100}) + (0.0031 \times p\text{aO}_2)\)
- $CvO_2$ = mixed venous oxygen content = \((1.39 \times Hb \times \frac{\%O_2\text{vHb}}{100}) + (0.0031 \times p\text{vO}_2)\)
- $CcO_2$ = capillary oxygen content = \((1.39 \times Hb \times K) + (0.0031 \times p\text{AO}_2)\)

$$K = \left(1 - \frac{\%COHb}{100}\right)$$ for $p\text{AO}_2 > 150$

$$\left(1 - \frac{\%COHb}{100}\right) - 0.01$$ for $p\text{AO}_2 125$ to $150$

$$\left(1 - \frac{\%COHb}{100}\right) - 0.02$$ for $p\text{AO}_2 < 125$

$p\text{AO}_2$ = see A-aDO$_2$ calculation.

**Reference range**
Normal values for physiologic shunt are between 2% and 5%.
OXYHEMOGLOBIN DISSOCIATION CURVE AND P\textsubscript{50}

**Definition**

The sigmoid oxyhemoglobin dissociation curve indicates the relationship between oxygen pressure and the percentage of hemoglobin bound with oxygen (Fig. 4).

The curve is derived from the Hill function which is used to calculate the percentage of oxyhemoglobin at a given pressure. This function can be shifted either to the left or to the right with respect to a condition of normality, depending upon various physical condition of the blood. In particular: pH, temperature, CO\textsubscript{2} content, 2,3 DPG, CO content (Fig. 5).

*Fig. 4 - Oxyhemoglobin dissociation curve.*
Fig. 5 - Factors influencing hemoglobin affinity for oxygen (shift to the right and to the left).

Fig. 6 - Variations of $P_{50}$ as a function of carboxyhemoglobin concentration.
As it can be seen in Fig.6 the shape itself of the oxyhemoglobin dissociation curve may change from sigmoid to hyperbolic if a great amount of carboxyhemoglobin is present. In order to quantify the amount of this shift the parameter $P_{50}$ has been introduced. This parameter indicates the pressure of oxygen at which the hemoglobin is 50% oxygenated in particular laboratory measuring conditions (37 °C, 40 mmHg pCO$_2$, pH 7.40).

A reduction below the normal value indicates a shift of the dissociation curve towards the left, while an increase means a shift to the right.

There are different methods to determine $P_{50}$. The one which is employed in our program uses the Hill equation taking measured values for pO$_2$ and %O$_2$Hb. The equation is:

$$P_{50} = 10^{\frac{\log \frac{\%O_2Hb}{100-\%O_2Hb} - 2.7 \log pO_2}{2.7}}$$

where 2.7 is the slope of the straight part of the Hill curve.

Note:
- For the calculation of the $P_{50}$ in the Synthesis, 1600 and BGE models, it is possible to replace in the above formula the parameter %O$_2$Hb (oxyhemoglobin fraction of total hemoglobin in the mixed venous blood sample) with the parameter %sO$_2$m (measured oxygen saturation of available hemoglobin in the mixed venous blood sample).
- Limits for %O$_2$Hb are 30 and 75

**Reference range**
The adult reference value is around 26.8 mmHg.
OPERATING PROCEDURE

The calculation of the special parameters is performed automatically by the Synthesis 15/25/35 (models that have already CO-OX cuvette on board). Instead, Synthesis 10/20/30, IL 1610/20/30/40/50/60 and BGE must be interfaced to 482 or 682 CO-Oximeters.

A sample of arterial heparinized blood and a sample of mixed venous heparinized blood from the same patient is required to obtain special parameters.

The following protocol must be observed: mix the first sample, carry out the sampling on the BG analyzer and immediately afterwards on the CO-Oximeter (with the exclusion of Synthesis models 15/25/35 which have the CO-Ox on board).

Enter the requested patient data -“PAT ID”, “FIO₂” and “sample type”. Follow the same procedure for the second blood sample.

When both analyses have been completed, press the key [SPECIAL PARAMETERS] (or “Mode 10” for 1610/1306) to have the parameters displayed (or printed).

For more informations and detailed instructions refer to the specific Operator’s Manuals.
### Arterial Blood Sample

**SYNTHESIS**  
29 SEP 98 15:52

Sample 00000097  
B.P. 742 mmHg  
Operator ID 5  
Arterial sample drawn at 15:53

#### PATIENT INFO
  - Patient ID 1
  - Name: Mario Rossi
  - FIO2 60.0 %

#### pH / BLOOD GASES
  - Measured at 37.0 °C
  - pH: 7.419
  - pCO2: 37.4 mmHg
  - pO2: 80 mmHg

#### ELECTROLYTES
  - Na⁺: 140 mmol/L
  - K⁺: 4.1 mmol/L
  - Ca++: 1.20 mmol/L
  - Cl⁻: 106 mmol/L

#### HCT (conductivity)
  - Hct: 46 %

#### CALCULATIONS
  - HCO₃⁻: 24.4 mmol/L
  - TCO₂: 25.6 mmol/L
  - BEb: -0.8 mmol/L
  - BEcf: -0.3 mmol/L
  - SBC: 25.3 mmol/L
  - sO₂C: 95.9 %
  - Ca²⁺ (pH 7.4): 1.21 mmol/L
  - Anion Gap: 16 mmol/L
  - pO₂ / FIO₂: 1.3

#### CO-OXIMETER
  - THb: 11.8 g/dL
  - O₂Hb: 96.0 %
  - COHb: 1.9 %
  - MetHb: 0.4 %
  - RHb: 1.7 %
  - T. Bil: 98.2 %
  - sO₂m: 15.7 Vol %O₂
  - O₂ct: 16.0 Vol %O₂

#### SPECIAL PARAMETERS
  - Arterial sample
  - Sample 00000097
  - CcO₂: 16.7 Vol %O₂
  - CaO₂: 15.4 Vol %O₂
  - CvO₂: 12.0 Vol %O₂
  - Qs/Qt: 27.3 %
  - a-VDO₂: 3.4 Vol %O₂
  - P₅₀: 26.9 mmHg

---

### Venous Blood Sample and Special Parameters

**SYNTHESIS**  
29 SEP 98 15:52

Sample 00000097  
B.P. 742 mmHg  
Operator ID 5  
Venous sample drawn at 15:55

#### PATIENT INFO
  - Patient ID 1
  - Name: Mario Rossi
  - FIO2 60.0 %

#### pH / BLOOD GASES
  - Measured at 37.0 °C
  - pH: 7.380
  - pCO₂: 45.5 mmHg
  - pO₂: 39 mmHg

#### ELECTROLYTES
  - Na⁺: 140 mmol/L
  - K⁺: 4.1 mmol/L
  - Ca++: 1.20 mmol/L
  - Cl⁻: 106 mmol/L

#### HCT (conductivity)
  - Hct: 46 %

#### CALCULATIONS
  - HCO₃⁻: 27.2 mmol/L
  - TCO₂: 28.6 mmol/L
  - BEb: 2.3 mmol/L
  - BEcf: 1.9 mmol/L
  - SBC: 26.1 mmol/L
  - sO₂C: 72.5 %
  - Ca²⁺ (pH 7.4): 1.19 mmol/L
  - Anion Gap: 16 mmol/L
  - pO₂ / FIO₂: 0.65

#### CO-OXIMETER
  - THb: 12.0 g/dL
  - O₂Hb: 73.7 %
  - COHb: 1.2 %
  - MetHb: 0.1 %
  - RHb: 25.0 %
  - T. Bil: 74.6 %
  - sO₂m: 12.3 Vol %O₂
  - O₂ct: 16.0 Vol %O₂

#### SPECIAL PARAMETERS
  - Arterial sample
  - Sample 00000097
  - CcO₂: 16.7 Vol %O₂
  - CaO₂: 15.4 Vol %O₂
  - CvO₂: 12.0 Vol %O₂
  - Qs/Qt: 27.3 %
  - a-VDO₂: 3.4 Vol %O₂
  - P₅₀: 26.9 mmHg

---

*Note: The P₅₀ value is calculated only if the mixed venous %O₂Hb value lies between 30 and 75. If not a series of question marks appear on the printout.*
(Below are reported the algorithms used for calculated parameters on Synthesis. For more details on 1600 series and GEM, refer to the relevant Operator’s Manuals)

**BG PARAMETERS AT PATIENT TEMPERATURE**

The following parameters are calculated when a patient temperature different from 37 °C (98.6 °F) is input by the operator.

- **pH at patient temperature.**
  \[
  \text{pH}_t = \text{pH}_{37} + (t-37) \times (-0.0147 - 0.0065 \times (\text{pH}_{37} - 7.4))
  \]
  where \( t \) = patient temperature in °C  
  \( \text{pH}_t \) = pH at patient temperature in pH units  
  \( \text{pH}_{37} \) = pH at 37 °C in pH units  
  note: for this algorithm pH must be used in pH units!

- **pCO₂ at patient temperature.**
  \[
  \text{pCO}_2t = \text{pCO}_2_{37} \times 10^{ \frac{0.019(t-37)}{0.019(t-37)}}
  \]
  where \( t \) = patient temperature in °C  
  \( \text{pCO}_2t \) = pCO₂ at patient temperature  
  \( \text{pCO}_2_{37} \) = pCO₂ at 37 °C  
  note: this algorithm works whatever unit is used for pCO₂

- **pO₂ at patient temperature.**
  \[
  \text{pO}_2t = \frac{\text{pO}_2_{37} \times 10^{\left(\frac{0.071}{0.037}\right)}}{9.72 \times 10^{-9} \times 10^{3.8 \log(pO_2_{37}) + 2.3}}
  \]
  where \( t \) = patient temperature in °C  
  \( \text{pO}_2t \) = pO₂ at patient temperature in mmHg  
  \( \text{pO}_2_{37} \) = pO₂ at 37 °C in mmHg  
  note: for this algorithm pO₂ must be used in mmHg!

**CALCULATED PARAMETERS BASED ON BG MEASURED VALUES ON BLOOD**

All the following parameters are calculated on blood samples (they are not given whenever “other” is selected as a sample type).

- **HCO₃⁻**
  The following parameter is given if pH and pCO₂ are measured.
  \[
  \text{HCO}_3^- = \text{pCO}_2 \times 10^{\left(\text{pH} - (pK_a + 1.5228)\right)}
  \]
  where \( pK_a \) = coefficient configurable by the operator in the range 6.00 ÷ 7.00  
  \( \text{pH} \) = measured value at 37 °C in pH units  
  \( \text{pCO}_2 \) = measured value at 37 °C in mmHg

- **TCO₂**
  The following parameter is given if pH and pCO₂ are measured.
  \[
  \text{TCO}_2 = \text{HCO}_3^- + 0.0307 \times \text{pCO}_2
  \]
  where \( \text{HCO}_3^- \) = calculated as indicated above  
  \( \text{pCO}_2 \) = measured value at 37 °C in mmHg.
• **BEb**
  The following parameter is given if pH and pCO₂ are measured.
  \[ BE_b = (1 - 0.014 \times THb) \times (HCO_3^- - 24 + (1.43 \times THb + 7.7) \times (pH - 7.4)) \]
  where
  \( pH \) = measured value at 37 °C in pH units.
  \( HCO_3^- \) = calculated as indicated above
  \( THb \) = value in mg/dL, measured by CO-OX or entered by the operator when CO-OX is unavailable.

• **BEecf**
  The following parameter is given if pH and pCO₂ are measured.
  \[ BE_{ecf} = HCO_3^- - 25 + 16.2 \times (pH - 7.4) \]
  where
  \( pH \) = measured value at 37 °C in pH units.
  \( HCO_3^- \) = calculated as indicated above

• **sO₂c**
  The following parameter is given if pH, pCO₂ and pO₂ are measured.
  \[ sO_2c = 100 \times \frac{p^3 + 150p}{p^3 + 150p + 23400} \]
  where
  \( p = pO_2 \times 10^{(0.48(pH-7.4)-0.0013(HCO_3^- -25))} \)
  with
  \( pH \) = measured value at 37 °C in pH units.
  \( pO_2 \) = measured value at 37 °C in mmHg.
  \( HCO_3^- \) = calculated as indicated above

• **SBC**
  The following parameter is given if pH, pCO₂ and pO₂ are measured.
  \[ SBC = 25 + 0.78 \times BE_b + 0.002 \times THb \times (s - 100) \]
  where
  \( s = O_2Hb \) value if CO-OX data are available. \( sO_2c \) value calculated as indicated above if CO-OX data are unavailable.
  \( BE_b \) = calculated as indicated above
  \( THb \) = value in mg/dL, measured by CO-OX or entered by the operator when CO-OX is unavailable.

**CALCULATED PARAMETERS BASED ON BG MEASURED VALUES ON ARTERIAL BLOOD**

The following parameters are calculated on arterial blood samples (they are not given whenever anything different from “arterial” is selected as a sample type).

• **A-aDO₂**
  The following parameter is given if pCO₂ and pO₂ are measured, FiO₂ is entered by the operator and the resulting calculated value is >0.
  \[ A - aDO_2 = 0.01 \times [FiO_2 \times BP_t - PCO_2t \times (125 - 0.25 \times FiO_2)] - pO_2t \]
  where
  \( BP_t = B.P. \times (0.4 + 10^{(0.0244xT-0.7659)}) \)
  \( FiO_2 \) = value entered by the operator
  \( pO_2t \) = value of pO₂ in mmHg at patient temperature
  \( T \) = value of patient temperature in °C entered by the operator
  \( B.P. \) = value of barometric pressure in mmHg.
• **pAO₂**
  The following parameter is given if pCO₂ and pO₂ are measured, FIO₂ is entered by the operator and A-aDO₂ is >0.

  \[ pAO₂ = A - aDO₂ + pO₂t \]

  where \( pO₂t \) = value of pO₂ in mmHg at patient temperature
  \( A-aDO \) = calculated as indicated above

• **RI**
  The following parameter is given if pCO₂ and pO₂ are measured, FIO₂ is entered by the operator and A-aDO₂ is >0.

  \[ RI = \frac{A - aDO₂}{pO₂t} \]

  where \( pO₂t \) = value of pO₂ in mmHg at patient temperature
  \( A-aDO \) = calculated as indicated above

**CALCULATED PARAMETERS BASED ON BG MEASURED VALUES ON EXPIRED GAS SAMPLES.**

The following parameters are presented when an expired gas sample is executed.

• **%CO₂**
  The following parameter is given if pCO₂ is measured

  \[ %CO₂ = \frac{pCO₂ \times 100}{B.P.-47} \]

  where \( pCO₂ \) = measured value at 37 °C in mmHg.
  B.P. = value of barometric pressure in mmHg.
  47 = partial pressure of water vapour at 37 °C in mmHg.

• **%O₂**
  The following parameter is given if pO₂ is measured

  \[ %O₂ = \frac{pO₂ \times 100}{B.P.-47} \]

  where \( pO₂ \) = measured value at 37 °C in mmHg.
  B.P. = value of barometric pressure in mmHg.
  47 = partial pressure of water vapour at 37 °C in mmHg.
CALCULATED PARAMETERS BASED ON BG and ELECTROLYTES MEASURED VALUES

• Ca++ (pH 7.4)
The following parameter is given if pH and Ca++ are measured and the value of pH is in the range 7.200 ÷ 7.600.

\[ Ca^{++}_{(pH\ 7.4)} = Ca^{++} \times 10^{A(7.4-pH)} \]

where
- \( A \) = coefficient configurable by the operator in the range 0 ÷ 9.999
- \( pH \) = measured value at 37 °C in pH units.
- \( Ca^{++} \) = measured value in mmol/L

• Anion Gap
The following parameter is given if pH, pCO2, Na+, K+ and Cl- are measured.

\[ \text{Anion Gap} = (Na^{+} + K^{+}) - (Cl^{-} + HCO_{3}^{-}) \]

where
- \( Na^{+} \) = measured value in mmol/L
- \( K^{+} \) = measured value in mmol/L
- \( Cl^{-} \) = measured value in mmol/L
- \( HCO_{3}^{-} \) = calculated as indicated at pag. 24

• Osmolality
The following parameter is given if Na+ and Glu are measured and BUN is entered by the operator.

\[ \text{Osm} = 1.86 \times Na^{+} + \frac{Glu}{18} + \frac{BUN}{2.8} + 9 \]

where
- \( Na^{+} \) = measured value in mmol/L
- \( Glu \) = measured value in mmol/L
- \( BUN \) = value entered by the operator in mg/dL

• THb
The THb is given as a calculated parameter only if it is not measured by CO-OX and Hct is measured.

\[ \text{THb} = \frac{Hct}{3} \]

where
- \( Hct \) = measured value in %.

CALCULATED PARAMETERS BASED ON CO-OX MEASURED VALUES

• RHb
RHb is measured on the internal CO-OX, but it is calculated when CO-OX data are received from an external CO-OX.

\[ \text{RHb} = 100 \times (O_{2}\text{Hb} + COHb + MetHb) \]

where
- \( O_{2}\text{Hb} \) = measured value in %.
- \( COHb \) = measured value in %.
- \( MetHb \) = measured value in %.
• $sO_2m$
\[
sO_2m = \frac{100 \times O_2Hb}{100 - (COHb + MetHb)}
\]
where $O_2Hb$ = measured value in %.
$COHb$ = measured value in %.
$MetHb$ = measured value in %.

• $O_2ct$
The following parameter is given when THb and $O_2Hb$ are measured
\[
O_2ct = K \times THb \times \frac{O_2Hb}{100}
\]
where $K$ = coefficient configurable by the operator in the range 1.00 ÷ 2.00
(factory set: 1.39).
$THb$ = measured value in mg/dL.
$O_2Hb$ = measured value in %.

• $O_2cap$
The following parameter is given when THb, $O_2Hb$, $COHb$ and MetHb are measured
\[
100 \times \frac{O_2ct}{sO_2m} = sO_2m
\]
where $O_2ct$ = calculated as indicated above
$sO_2m$ = calculated as indicated above

• $Hct$
$Hct$ is calculated only when THb is measured on the CO-OX and $Hct$ measured is not available.
$Hct = THb \times 3$
where $THb$ = measured value in mg/dL

CALCULATED PARAMETERS BASED ON BG + CO-OX MEASURED VALUES

The following parameter is presented only if the sample is identified as “venous” and the value of $O_2Hb$ is in the range 30 ÷ 75 %.

• $P_{50}$
\[
P_{50} = 10^{\frac{\log \frac{O_2m}{100}}{2.7} - 2.7 \log pO_2t})}
\]
where $pO_2t$ = value of $pO_2$ in mmHg at patient temperature
$O_2Hb$ = measured value in %.

Note: In instrument configuration the operator can select to use the value of $sO_2m$, calculated as indicated above in place of $O_2Hb$ with the same rules.
SPECIAL PARAMETERS BASED ON ARTERIAL AND MIXED VENOUS BLOOD ANALYSIS

The following parameters are presented only when an AV pair is identified.

• CcO₂

\[ CcO₂ = THb_M \times \alpha_A + \beta_A \]

where

\[ THb_M = \frac{THb_A + THb_V}{2} \]

\( THb_A = \text{THb of arterial sample in mg/dL} \)

\( THb_V = \text{THb of venous sample in mg/dL} \)

\[ \alpha_A = 1.39 \times \left(1 - \frac{COHb_A}{100}\right) - C \]

\( COHb_A = \text{COHb of arterial sample} \)

\( C = 0 \) if \( pAO₂ > 150 \)

\( C = 0.01 \) if \( 125 < pAO₂ < 150 \)

\( C = 0.02 \) if \( pAO₂ < 125 \)

\[ \beta_A = 0.0031 \times pAO₂ \]

\( pAO₂ = \text{calculated on arterial sample as indicated at pag. 26} \)

• CaO₂

\[ CaO₂ = THb_M \times \tau_A + \sigma_A \]

where

\[ THb_M = \frac{THb_A + THb_V}{2} \]

\( THb_A = \text{THb of arterial sample in mg/dL} \)

\( THb_V = \text{THb of venous sample in mg/dL} \)

\[ \tau_A = 0.0139 \times O₂Hb_A \]

\( O₂Hb_A = \text{O₂Hb of arterial sample} \)

\[ \sigma_A = 0.031 \times pO₂t_A \]

\( pO₂t_A = \text{pO₂ of arterial sample in mmHg at patient temperature} \)

• CvO₂

\[ CvO₂ = THb_M \times \tau_V + \sigma_V \]

where

\[ THb_M = \frac{THb_A + THb_V}{2} \]

\( THb_A = \text{THb of arterial sample in mg/dL} \)

\( THb_V = \text{THb of venous sample in mg/dL} \)

\[ \tau_V = 0.0139 \times O₂Hb_V \]

\( O₂Hb_V = \text{O₂Hb of venous sample} \)

\[ \sigma_V = 0.031 \times pO₂t_V \]

\( pO₂t_V = \text{pO₂ of venous sample in mmHg at patient temperature} \)

• \( Q_{sp}/Q_t \)

\[ Q_{sp}/Q_t = 100 \times \frac{CcO₂ - CaO₂}{CcO₂ - CvO₂} \]

where

\( CcO₂ = \text{calculated as indicated above} \)

\( CaO₂ = \text{calculated as indicated above} \)

\( CvO₂ = \text{calculated as indicated above} \)

• a-\( \Delta DO₂ \)

\[ a - \Delta DO₂ = CaO₂ - CvO₂ \]

where

\( CaO₂ = \text{calculated as indicated above} \)

\( CvO₂ = \text{calculated as indicated above} \)
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APPENDIX

REFERENCE VALUES

7.400
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140
4.0
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<th>VENOUS BLOOD</th>
<th>Units</th>
<th>Conversion factors</th>
<th>Specimen/notes</th>
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<td>7.32-7.42 (48-38)</td>
<td>pH units (H+ =Eq/L or mmol/L)</td>
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<td>pCO₂</td>
<td>35-45 (4.66-5.99)</td>
<td>41-51 (5.45-6.78)</td>
<td>mmHg (KPa)</td>
<td>mmHg x 0.133 = kPa</td>
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<tr>
<td>pO₂</td>
<td>80-100 (10.7-13.4)</td>
<td>24-40 (3.19-5.32)</td>
<td>mmHg (kPa)</td>
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<tr>
<td>Na⁺</td>
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<td>135-145</td>
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<tr>
<td>K⁺</td>
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<td>3.5-5.1 s (3.4-4.5 p)</td>
<td>mEq/L (mmol/L)</td>
<td>mEq/L = mmol/L</td>
<td>serum</td>
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<tr>
<td>Ca⁺</td>
<td>1.13-1.32 (4.52-5.28)</td>
<td>1.13-1.32 (4.52-5.28)</td>
<td>mmol/L (mg/dL)</td>
<td>mmol/L / 0.25 = mg/dL</td>
<td>plasma, whole blood</td>
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<td>pH (pH7.4)</td>
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<td>Cl⁻</td>
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<td>Glu</td>
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<tr>
<td>Total Bilirubin</td>
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<td>mg/dL x 17.1 = µmol/L</td>
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<td>10-14 (171-239)</td>
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<td>2-6 (34-103)</td>
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<td>6-10 (103-171)</td>
<td>6-10 (103-171)</td>
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<td>4-8 (68-137)</td>
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<td>Hct</td>
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### Reference Values

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<tr>
<th>PARAMETER</th>
<th>ARTERIAL BLOOD</th>
<th>VENOUS BLOOD</th>
<th>Units</th>
<th>Conversion factors</th>
<th>Specimen/notes</th>
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<td>THb</td>
<td>13.5-18.0 (12-16)</td>
<td>13.5-18.0 (12-16)</td>
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<td>O₂Hb</td>
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<td>HCO₃⁻</td>
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<td>always &gt; %O₂-Hb</td>
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<th>PARAMETER</th>
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