



Paramedic Resource Manual

OXYGEN DELIVERY SECTION TWO

2014 Update by
Ontario Base Hospital Group Education Subcommittee

OBJECTIVES: OXYGEN DELIVERY

The objectives indicate what you should know, understand and be prepared to explain upon completion of this module. The self-assessment questions and answers will enable you to judge your understanding of the material.

Upon completion of this module, the student should be able to:

1. briefly explain the principle of partial pressures of gases.
2. describe the factors affecting oxygen and carbon dioxide transport and release in the body.
3. briefly describe the factors affecting oxygen dissociation.
4. define hypoxia and briefly explain the difference between the two main types of hypoxia.
5. list the causes of hypoxia and give examples.
6. briefly describe the chemical control of ventilation.
7. explain the reason for the use of non-rebreather masks and nasal cannulae in the A.L.S. system.
8. Identify and explain the function of an aerosol mask and nebulizer.
9. State the flow rates and oxygen concentration achieved with:
 - a) Nasal cannulae
 - b) Non-rebreather mask
 - c) Aerosol mask
 - d) Bag-valve-mask.
10. compare and contrast the bag-valve-mask with the pressure-driven (powered) system.
11. state the reasons for using humidified oxygen.
12. Accurately calculate the duration of an oxygen cylinder, given the flow rate, cylinder size and gauge pressure.
13. Apply the information within the above objectives to clinical situations.

If you have studied this subject previously, you may test your ability using the self-assessment questions. If you are able to obtain 90% or greater, you may choose not to do the unit and merely review the sections, or parts of sections, where weakness may exist. If you obtain less than 90%, it is recommended that the module be done in its entirety, stressing areas where more review is needed.

INTRODUCTION

The unit on the respiratory system examines both the anatomical and physiological aspects of the respiratory system important in pulmonary mechanics and ventilation. This unit is intended to be a continuation of the discussion on the respiratory system focusing on the principles of gas transport, factors affecting transport, the chemical control of the respiration and the practical application and usage of oxygen delivery systems.

A review of the respiratory system, as well as a brief review of acid-base balance, is suggested before attempting this unit.

PARTIAL PRESSURES

PRINCIPLE

Gas molecules are in fluid motion all around us. The earth's atmosphere is made up of many different gases, each one comprising a certain percentage of the total amount.

Like other molecules, gases have weight and create a downward force as a result of the earth's gravity. The total downward force of these gases is known as **atmospheric pressure**.

At sea level, this downward pressure is sufficient to support a column of mercury (Hg) 760 millimeters (mm) high. Therefore, 1 Atmosphere is equal to 760 mmHg.

Gases are also measured in "torr" units. One torr unit equals one mmHg. Therefore:

$$1 \text{ Atmosphere} = 760 \text{ mmHg} = 760 \text{ torr}$$

It is often important to calculate the pressure of a single gas of the mixture. This value is known as the **PARTIAL PRESSURE** (often called the TENSION) of that gas. The partial pressure of any gas is the pressure which it would exert if it were alone and unaffected by changes in other gases.

There are a number of gas laws which help summarize the behaviour of gases. Relevant to this discussion is Dalton's Law which states: "The total pressure of a gas mixture is equal to the sum of the partial pressures of the component gases".

CALCULATION OF PARTIAL PRESSURES

To calculate the partial pressure (P) of a particular gas, multiply the total pressure (P_T) of all the gases times the fraction of composition of the gas you are trying to find.

EXAMPLE 1:

At sea level (1 atm) the total gas pressure (P_T) is 760 mmHg.

Oxygen is approximately 20.93% of the total atmospheric composition.

Therefore, the partial pressure of O_2 (PO_2) is:

$$760 \times 0.2093 = 159.1 \text{ mmHg}$$

$$159.1 \text{ mmHg} = \text{the approximate } PO_2 \text{ in atmospheric air}$$

EXAMPLE 2:

The P_T of the two gases in the box equals 760 mmHg.

Gas (a) equals 2/10 or 20% of the P_T .

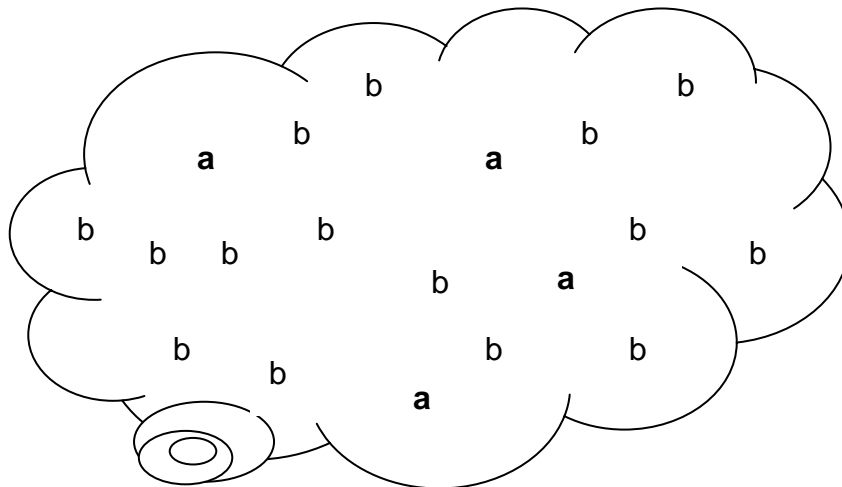
Gas (b) equals 8/10 or 80% of the P_T .

Therefore, the partial pressure of gas (a) is:

$$0.20 \times 760 = 152 \text{ mmHg}$$

the partial pressure of gas (b) is:

$$0.80 \times 760 = 608 \text{ mmHg}$$



COMPOSITION OF AIR

The understanding of partial pressures, as they relate to respiratory physiology, requires a comparison of air composition between the atmospheric and the alveolar air.

SPECIFIC GASES	DRY ATMOSPHERE AIR (%) (partial pressure)		ALVEOLAR AIR (%) (partial pressure)	
Nitrogen (N ₂)	79.03	600.60 mmHg	74.9	569.24 mmHg
Oxygen (O ₂)	20.93	159.10 mmHg	13.6	103.36 mmHg
Carbon Dioxide (CO ₂)	0.04	.30 mmHg	5.3	40.28 mmHg
Water (H ₂ O)	-	-	6.2	47.12 mmHg
Total	100.00	760.00 mmHg	100.0	760.0 mmHg

From Table 1, it can be seen that the total pressure of the atmospheric air and the alveolar air is the same. However, when comparing the two, it is important to note the difference in the percentage and partial pressure of each of the component gases.

Above any solution is the vapour of the solution (solvent) itself. This is known as the **VAPOUR PRESSURE**. Under equilibrium conditions, the partial pressure of a gas in a liquid is equal to the partial pressure of the gas above the liquid. The vapour pressure of water at 37°C is approximately 47 mmHg. The airways of the lungs, including the alveoli, are fully saturated with water vapour, **i.e.** 100% relative humidity. This means a partial pressure of water vapour within these airways equaling approximately 47 mmHg. This water vapour pressure must appear as part of the total gas pressure and this is reflected by a decrease in the partial pressures of the other gases within the alveoli.

Another gas law which may help to explain the relationship of partial pressures above and within a solution is Henry's Law which states: "The quantity of a gas that dissolves in a volume of liquid is directly proportional to the partial pressure of that gas, the pressure remaining constant".

DIFFUSION

It is within the alveoli that gas exchanged takes place. The exchange of gases between the alveoli and the venous blood returning to the lungs is a result of the gases diffusing across the alveolar and capillary membranes.

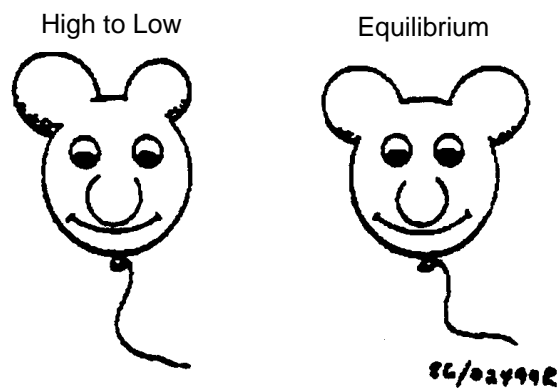
The ability of a gas to diffuse across these membranes and either into or out of the blood is dependent upon five factors. Certain pathologies such as COPD, pulmonary edema, tumors, fibrosis, etc. can all affect the efficiency of the gas transfer.

The factors affecting diffusion are:

1. The solubility of the gas in the fluid.
2. The concentration or pressure gradient.
3. The amount of surface area available.
4. The thickness of the membrane.
5. The temperature of the fluid.

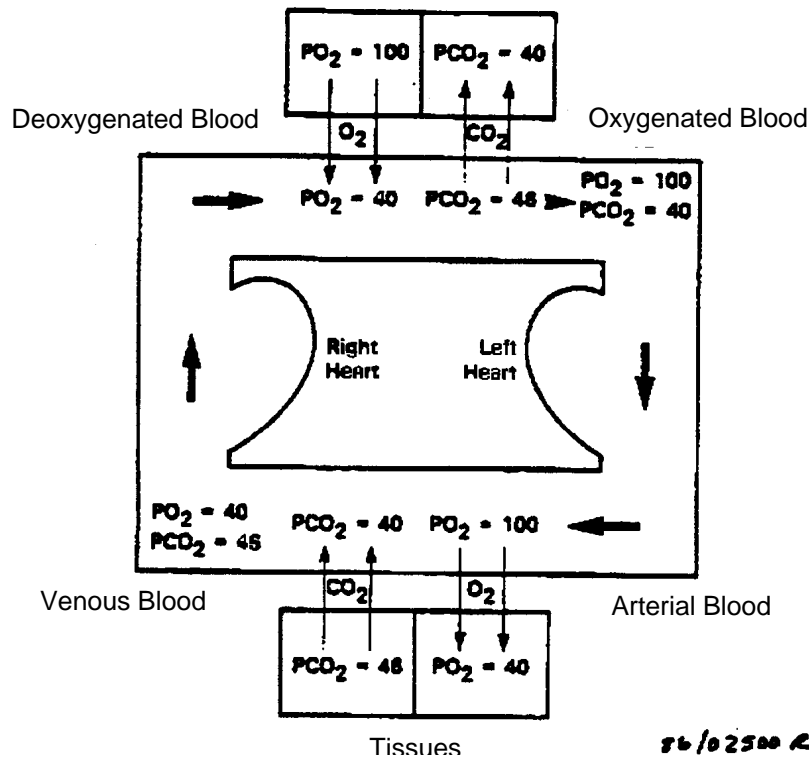
Gases diffuse from an area of high concentration (pressure) to an area of low concentration (pressure) until an equilibrium is attained. In this way, essential gases move into and out of the blood via the lungs.

FIGURE 1: DIFFUSION OF GASES



When examining the partial pressure of gases within the blood, it can be seen (Figure 2) that the partial pressure of oxygen within the venous blood (PvO_2) is about 40 mmHg. As the blood enters the pulmonary capillaries, via the heart and pulmonary arteries, it will come into contact with the alveolar air containing a PO_2 of approximately 100 mmHg. The concentration difference between the two causes the oxygen to diffuse from the alveolus to the blood until an equilibrium is reached. Blood now leaving the lungs, via the pulmonary veins, will be pumped by the heart into the arterial system.

FIGURE 2: GAS PRESSURE RELATIONSHIPS BETWEEN THE LINGS AND TISSUES



The PO₂ of the newly oxygenated blood will be very close to that of the alveolus. However, there is a slight reduction due to the normal physiologic shunt (see Respiratory unit). Lung damage or disease may cause a dramatic increase in the amount of blood shunted through the lungs. This would cause a further lowering of the partial pressure of oxygen within the arterial blood (PaO₂).

Oxygenated blood is taken to the tissues, via the arterial and capillary systems and is exchanged as a direct result of the gas pressure differences. The PO₂ within the tissues can be extremely variable and is dependent upon the metabolic activity. Average PO₂ for tissues is considered to be approximately 40 mmHg, however, this could be considerably lower in very active tissues.

Carbon dioxide (CO₂) is a by-product of cell metabolism. The CO₂ produced by the cell diffuses into the venous blood giving it a PCO₂ of about 46 mmHg. As this blood comes in contact with the alveolar air (having a PCO₂ of 40 mmHg), there is a net diffusion of carbon dioxide out of the blood and into the lungs.

GAS TRANSPORT

OXYGEN TRANSPORT TO THE TISSUES

At the normal partial pressure of 100 mmHg, oxygen is relatively insoluble in plasma. Only about 0.3 mL of oxygen dissolves in 100 mL of plasma. The small amount of oxygen that is dissolved is totally inadequate to supply the demand by the tissues.

There are two factors which determine the quantity of oxygen delivered to the tissues. These are the:

- o Blood flow (perfusion)
- o Concentration of hemoglobin and the affinity of oxygen for it (oxygenation).

Actual blood flow is determined by the integrity of the cardiovascular system. Various influences upon the cardiovascular system which affect cardiac output and the degree of vasoconstriction all affect blood flow.

Hemoglobin is the red pigment found within the red blood cells (erythrocytes). As a result of its chemical configuration, hemoglobin has a strong affinity for oxygen and is the principal carrier in the blood. As stated above, only about 0.3 mL of oxygen is physically dissolved in 100 mL of blood. By contrast, hemoglobin will combine with 19-20 mL of oxygen per 100 mL of blood *usually expressed as volumes percent). This oxygen bound to hemoglobin accounts for approximately 97-98% of the total O_2 carried, when the PO_2 is 100 mmHg.

Hemoglobin is a complex molecule consisting of heme and globin portions. In each heme portion there are four atoms of iron, each capable of attaching to a molecule of oxygen. When oxygen is attached to deoxygenated hemoglobin (Hb), it becomes oxyhemoglobin (HbO_2). Oxyhemoglobin is formed in the alveolar capillary beds due to a high PO_2 and a decreased PCO_2 . The mechanism by which oxygen is released from hemoglobin for diffusion to the tissues is discussed in greater detail under the "Bohr Effect" on page 67. Figures 3 and 4 illustrate the transport of oxygen.

FIGURE 3: ASSOCIATION/DISSOCIATION OF O_2 AND HbO_2

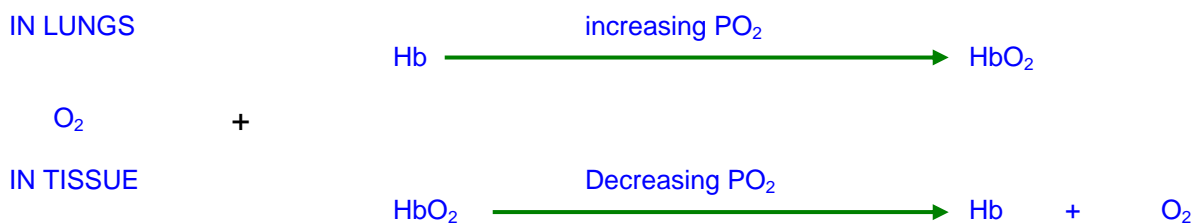
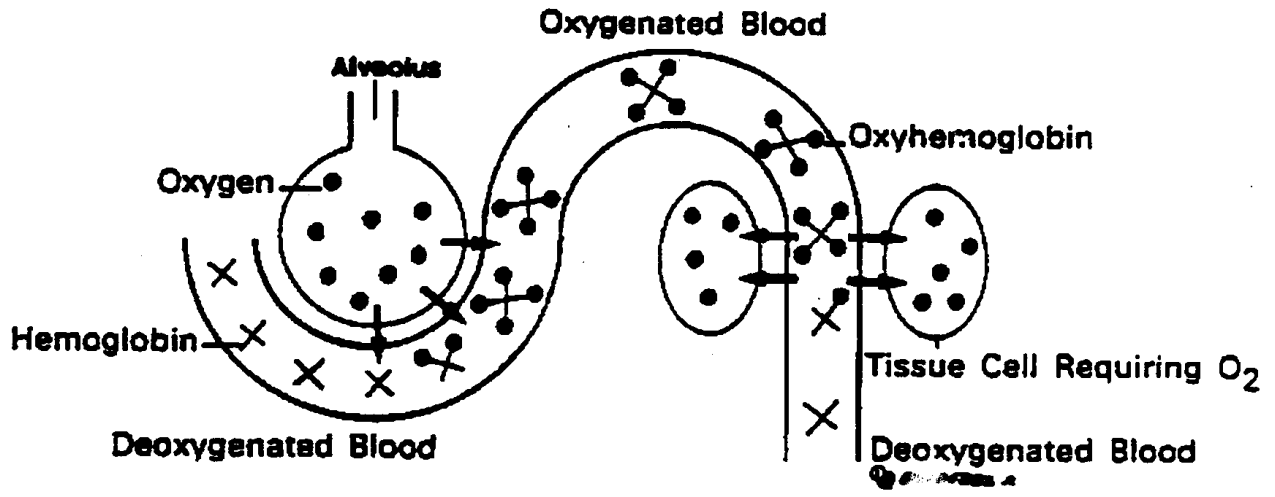


FIGURE 4: OXYGEN TRANSPORT



OXYGEN DISSOCIATION

The way in which oxygen is taken up and given off can be seen graphically using an oxygen-hemoglobin dissociation curve. The resulting S shaped curve will show the percentage of saturated hemoglobin (left vertical axis) at varying partial pressures of oxygen (horizontal axis). Examples of this curve are shown in Figure 5.

At maximal saturation, each gram of hemoglobin has an oxygen carrying capacity of 1.34 mL/100 mL of blood ($PO_2 = 760$ mmHg), or 4 O_2 molecules per hemoglobin. The average adult has between 14-16 gm of hemoglobin for every 100 mL of blood.

Venous blood has a PO_2 of 40 mmHg at rest. This means that 75% of the hemoglobin is saturated in “deoxygenated” blood.



For Interest Only

Of a 4.6 vol % of O_2 used by the tissues, about 4.4% was released from the hemoglobin and the further 0.2% came from the dissolved O_2 in the plasma. With the tissues using such a small percent of the total available O_2 , it can be seen that there is a large reserve available for increased tissue demands, and that very active conditions can cause the PvO_2 to be as low as 10-20 vol %.



FACTORS AFFECTING AFFINITY OF OXYGEN FOR HEMOGLOBIN

The three major factors which affect the affinity of oxygen for hemoglobin are **pH** (blood acidity), **PCO_2** and **temperature**. The oxygen-hemoglobin dissociation curve (Figure 5) is affected by any one of these factors. The curve will shift either:

- o Downward and to the right
- OR
- o Upward and to the left.

An increase in hydrogen ion concentration (lowering the pH) causes the blood to be more acidic which causes the curve to shift downward and to the right. When the curve shifts downward and to the right, as in an acidotic state, O_2 doesn't bond as easily or as strongly at the level of the lungs, however O_2 is more readily released to the tissue levels. Increases in temperature also have a similar effect on the curve.



Clinical vignette

Even though hemoglobin's affinity for O_2 may be diminished in an acidotic state, we can help to compensate for that by providing supplemental O_2 . Hyperventilation may also be indicated in cases of respiratory acidosis, as blowing off CO_2 will cause an increase in the blood pH (every \downarrow in CO_2 of 10 mmHg = \uparrow in pH or 0.08).

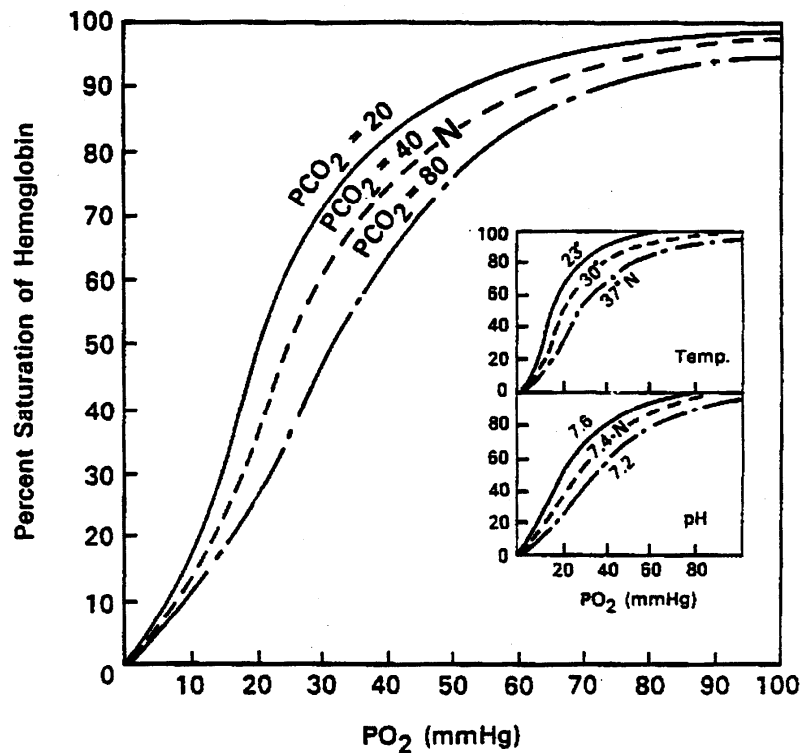
Conversely, a decrease in hydrogen ion concentration (increase in pH or alkalosis), a reduction in PCO_2 , or lowering of the temperature will cause the curve to shift upward and to the left. This causes oxygen bind more readily and more tightly to hemoglobin at the level of the lungs, however, O_2 is not as readily released from hemoglobin at the tissue level.



Clinical vignette

Hyperventilation (blowing off CO_2) may actually impair oxygenation at the tissue level as O_2 becomes too tightly bound to hemoglobin. Hence providing O_2 to a patient who is hyperventilating is not only indicated, but critically important for increasing the amount of dissolved O_2 in blood plasma to make it available at the tissue level.

FIGURE 5: EFFECT OF CO_2 , Ph AND TEMPERATURE ON OXYGEN-HEMOGLOBIN DISSOCIATION



N = Normal

86/02565 R

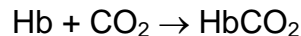
Nature has provided us with a protective mechanism when it comes to oxygen transport. As seen by the flatness at the top of the curve, slight natural variances in alveolar PO_2 will not affect, to any significant degree, the amount of oxygen carried by the hemoglobin.

CARBON DIOXIDE TRANSPORT

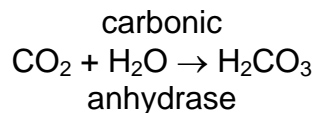
Carbon dioxide is a byproduct of normal aerobic cellular metabolism. Under resting conditions, each 100 mL of blood gives up 4-5 mL of CO₂ in the lungs. Carbon dioxide is very acidic and is transported by the blood until it can be eliminated from the body by either the lungs or excreted by kidneys. Inability of the body to excrete CO₂ would result in the blood becoming too acidic to sustain life. Carbon dioxide is transported in the blood in three ways. These are:

- o Carried in the form of bicarbonate
- o Combined with hemoglobin (carbaminohemoglobin)
- o Dissolved in plasma.

Although carbon dioxide is almost 20-fold more soluble than oxygen in plasma, only 7-10% is carried in this form. A larger amount (23-25%) diffuses into the red blood cell and combines with hemoglobin (Hb) to form carbaminohemoglobin (HbCO₂).



The largest amount of carbon dioxide (65-70%) is carried in the form of bicarbonate (HCO₃⁻). This reaction occurs quite slowly in plasma but upon entering the red blood cell the reaction is increased almost 1000-fold by the assistance of the enzyme carbonic anhydrase.



Carbon dioxide combines with water to form carbonic acid. The carbonic acid (H₂CO₃) then dissociates into a hydrogen ion (H⁺) and a bicarbonate ion (HCO₃⁻).



The free hydrogen ions produced by this reaction are buffered primarily by the deoxyhemoglobin. The bicarbonate ions formed diffuse into the plasma. As the bicarbonate ions move out of the cell chloride ions (Cl⁻) move into the cell in a 1:1 relationship. This phenomenon is known as the CHLORIDE SHIFT. It occurs so that electrochemical neutrality is maintained within the cell. In the lungs this chemical reaction reverses as CO₂ is expelled.

BOHR EFFECT

The Bohr effect describes the changes in the affinity of oxygen to bind to hemoglobin as a result of the shift in blood pH that occurs on a breath by breath basis. Changes in hemoglobin to oxygen affinity occur at both the level of the lungs and the tissues.

Think of hemoglobin as a MAGNET that's affected by blood pH.

Normal pH is: 7.35 - 7.45
< 7.35 = acidotic
> 7.45 = alkalotic

- when we exhale, we blow off CO₂ and a shift of the blood's pH toward the alkaline side occurs
- when the blood is more alkaline, hemoglobin has a greater affinity (*stronger magnet*) for O₂ and thus O₂ is drawn toward hemoglobin at the alveolar/capillary level.
- when the blood reaches the tissue level, CO₂, a by-product of cellular metabolism, diffuses from the tissue to the capillary blood
- this shifts the blood pH toward the acidic side which weakens hemoglobin's hold on oxygen (*weaker magnet*)
- blood (hemoglobin) that shifts toward the acidic side of pH gives up O₂ readily to the tissues

The Bohr effect occurs on a breath by breath basis, facilitating the binding and releasing of oxygen from hemoglobin.

SUMMARY

ALKALINE STATE

- hemoglobin becomes a stronger magnet, drawing O₂ toward it
- if the blood remained alkaline at the tissue level, it would not release O₂ to the tissues readily (e.g. hyperventilation makes the blood alkaline, as does administering sodium bicarbonate, excessive vomiting, etc)

ACIDOTIC STATE

- when the blood is acidic, hemoglobin becomes a weak magnet and does not pick up O₂ as readily
- we attempt to compensate for this by providing the patient with supplemental oxygen which increases the amount of O₂ dissolved in blood plasma for transport.
- if blood is acidic at the tissue level, O₂ bound to hemoglobin is released to the tissue easily.



Clinical vignette

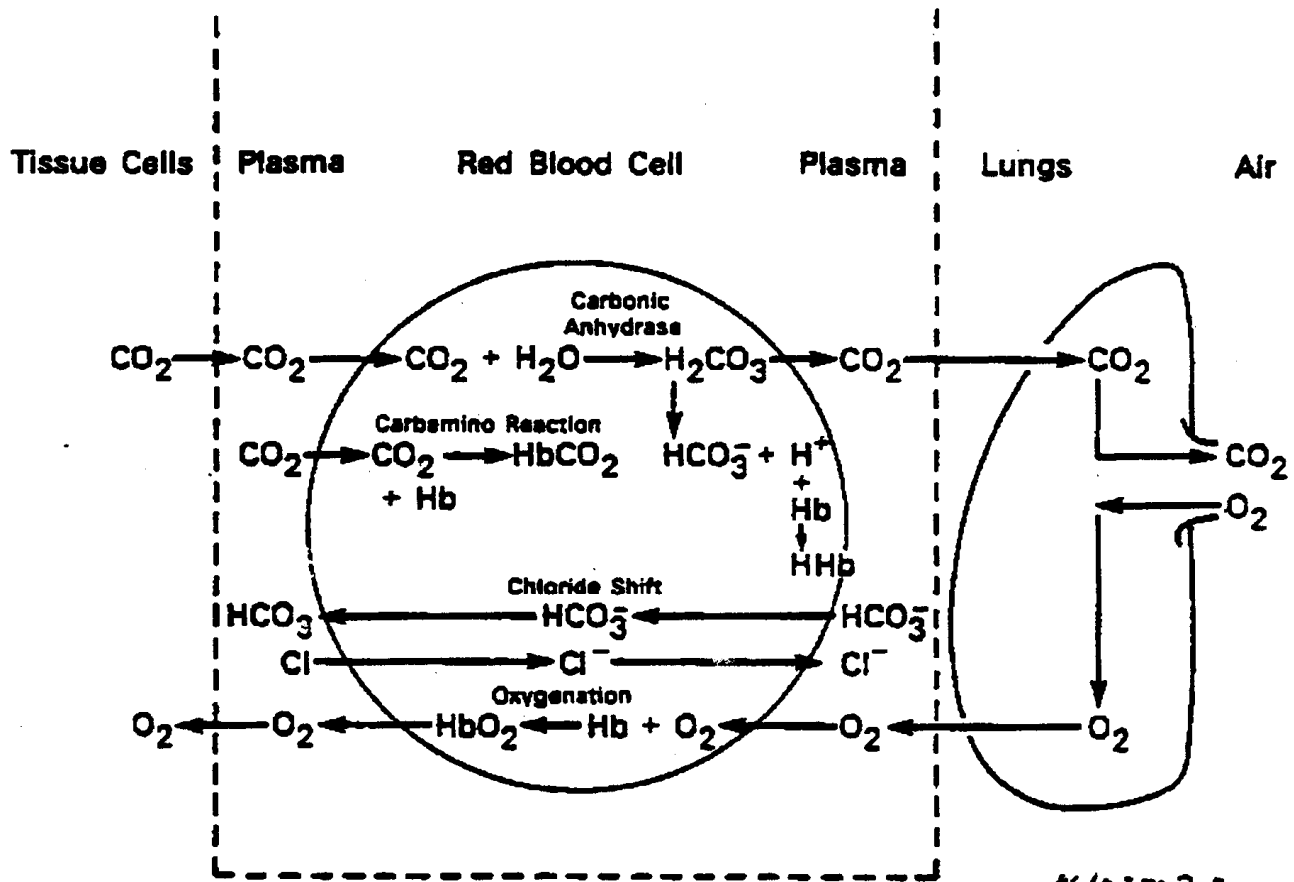
Hyperventilation, contrary to popular belief, is not defined by the respiratory rate. i.e. a patient who is breathing at a faster than "normal" rate (e.g. an adult breathing at 40 breaths per minute), is not necessarily hyperventilating.

Hyperventilation is defined as a Minute Volume (rate x tidal volume) that exceeds the body's metabolic demands.

Using the previous example, an adult who is breathing at a rate of 40 BPM with a very low tidal volume (shallow breathing) may in fact be **hypoventilating** and in need of ventilatory assistance.

When encountering a patient who is breathing fast, it's important to not assume that they're hyperventilating. It's equally important not to assume that their breathing needs to be coached, as their breathing pattern and minute volume is likely a compensatory response to an underlying disorder.

FIGURE 6: GAS TRANSPORT SUMMARY



HYPOXEMIA

Hypoxemia is identified by a blood gas analysis with a partial pressure of oxygen in the arterial blood lower than normal (<80 mmHg) and usually less than 90% oxygen saturation.

HYPOXIA

The term hypoxia can be generally defined as a state of oxygen deficiency or lack of oxygen. This reduced or insufficient oxygen supply to the tissues can cause impairment of bodily functions which may become irreversible if allowed to go unmanaged.

There are four types of hypoxia, each of these having a number of possible causes:

- o Hypoxic Hypoxia
- o Hypemic Hypoxia
- o Stagnant Hypoxia
- o Histotoxic Hypoxia.

A patient with oxygen deficiency may be suffering from a single cause or any combination of causes from one or more types of hypoxia.

- o **Hypoxic Hypoxia:** Breathing air or a gas which contains a lower than normal PO₂, **e.g.** high altitudes, rebreathing in a closed space.
- o Decrease in pulmonary ventilation, **e.g.** pneumothorax, partial airway obstruction, drug induced respiratory depression.
- o Abnormal lung function, **e.g.** asthma, fibrotic disease, fluid filled alveoli as with pulmonary edema, pneumonia, hemorrhage, drowning.
- o Arteriovenous shunting, **e.g.** some congenital heart defects allow for mixing of arterial and venous blood.
- o **Hypemic Hypoxia:** Reduced or altered Hb. In this case, blood does not have a normal O₂ carrying capacity. There is either a reduced concentration of hemoglobin (anemia) or the hemoglobin that is there, has a reduced ability to chemically unite with oxygen. Some common causes are:
 - Any type of anemia causing a reduction in Hb concentration.
 - Certain poisonings which chemically alter Hb.
 - Hb combined with a gas other than O₂, **e.g.** carbon monoxide

- o **Stagnant Hypoxia:** Any shock state in which there is widespread inadequate tissue perfusion, and hence inadequate tissue oxygenation. This form of hypoxia refers to end organ perfusion. With this type of hypoxia, both the O₂ carrying capacity and the PO₂ may be normal. What causes this problem is an extreme blood flow deficit. This serious lack of blood flow may be localized to a specific region or may be generalized throughout the body. Some of the major causes are:
 - o General – hypovolemic shock, cardiogenic shock
 - o Localized – thrombosis, embolus, vasoconstriction.

- o **Histotoxic Hypoxia:** While the blood's ability to pick up and transport O₂ may remain unaffected, a problem may also exist at the cellular level. An action by a toxic substance may prevent the diffusion of O₂ into the cells or may prevent the cells from utilizing oxygen. Cyanide is a poison which will cause this type of hypoxia.

PHYSICAL FINDINGS ASSOCIATED WITH TISSUE HYPOXIA

1. CNS impairment – restlessness, confusion, unsteady gait, slurred speech, stupor, coma.
2. Tachycardia (early) – ventricular dysrhythmias, and bradycardia (late).
3. Tachypnea, diaphoresis, pallor with or without cyanosis.



Clinical vignette

Cyanosis, due to the colour of deoxygenated blood, may be present in either type of hypoxia. It should be noted that cyanosis may be absent or reduced in the anemic patient, or the patient poisoned with carbon monoxide.

CHEMICAL CONTROL OF VENTILATION

As concentrations of carbon dioxide, oxygen and hydrogen ions vary in the blood, the respiratory system adjusts in an attempt to maintain normal tissue concentrations. The respiratory center will respond to elevated PCO_2 , reduced PO_2 or a lowered pH by increasing alveolar ventilation.

CARBON DIOXIDE

The most powerful stimulant to directly affect the respiratory center is CO_2 . Even a small increase, as little as 1%, can increase the respiratory minute volume whereas a small change in PO_2 has almost no effect. Conversely, if one were to voluntarily hyperventilate, causing the PCO_2 to fall below normal, respirations would cease until the PCO_2 is built up again. This situation can also occur when patients are artificially hyperventilated with adjunctive ventilatory equipment.

HYDROGEN IONS

The pH (acidity) of the blood also has a powerful effect on the respiratory center. Carbon dioxide and hydrogen ion concentration rise and fall together causing a combined effect in the control of respirations. Carbon dioxide combines with water to form carbonic acid, which can then dissociate into free hydrogen ions and bicarbonate:



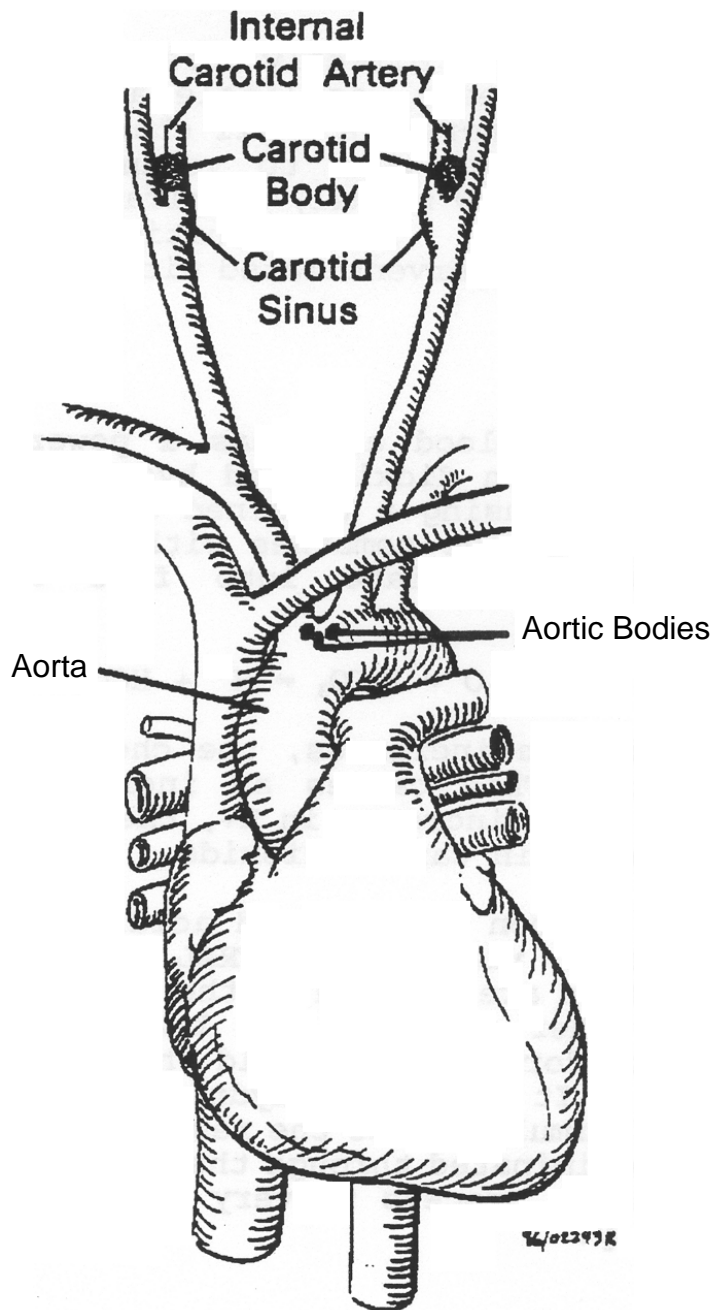
When the CO_2 concentration increases, the chemical reaction (above) shifts to the right. This causes an increase in hydrogen ions (acidity). If there is an increase in H^+ , the reaction shifts to the left causing an increase in carbon dioxide.

The concentration of carbon dioxide and acidity of the blood affect the respiratory center via the CENTRAL CHEMORECEPTORS. These chemosensitive receptors are located in the centerolateral surface of the medulla and on other areas of the brainstem. Carbon dioxide combines with water to form carbonic acid which then breaks down into H^+ and bicarbonate. It is these hydrogen ions that excite the chemoreceptors. The stimulation of the respiratory center causes more carbon dioxide to be eliminated through the lungs, causing a reduction in acidity. This entire process is very important in the acid-base regulation of the body.

OXYGEN

Within the process of respiratory control, the role of oxygen is less important. Changes in the blood pH and levels of carbon dioxide are always fluctuating. These changes affect the chemoreceptors thereby stimulating ventilation in an attempt to maintain normal arterial oxygenation and normal body PH. However, if the PaO_2 falls below 70 mmHg (steep portion of the O_2 curve) then there is a chemical stimulation of the PERIPHERAL CHEMORECEPTORS. These receptors, located in the carotid and aortic bodies, sense the reduction in PaO_2 and stimulate the respiratory center, via nerve fibers, to increase ventilation.

FIGURE 7: PERIPHERAL CHEMORECEPTORS



OXYGEN DEPRIVATION

Oxygen is essential to life. It is a colourless, odourless and tasteless gas, which supports combustion. Further, it is one of the most powerful drugs used by prehospital personnel – in many cases it can make the difference between life and death.

Oxygen deficiency can have an insidious onset giving little or no warning. It causes an impairment of judgement which may not allow the patient to realize what has happened. There are both subjective and objective signs of oxygen deprivation.

Subjective signs of oxygen deprivation are: dizziness, headache, restlessness, air hunger, visual changes, auditory changes, tingling, apprehension.

Objective signs of oxygen deprivation are: increased ventilatory function, unsteady gait, tachycardia (early), dysrhythmias, cyanosis (late), bradycardia and hypertension (late), unconsciousness (late).



Clinical vignette

Oxygen therapy should be initiated on any patient who is suspect of having one or more of the above signs.

To Review the Rationale for Oxygen Therapy

The purposes of oxygen therapy are to:

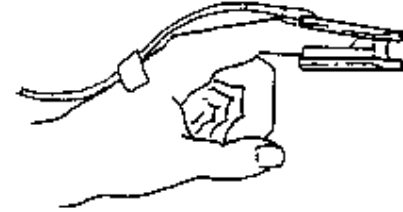
1. Increase PO_2 in the alveoli and the blood.
2. Reduce the ventilatory workload.
3. Reduce the myocardial workload.

The major function of the cardiovascular and respiratory system is to both supply oxygen to the tissues and remove metabolic waste. Reducing the workload causes a decrease in oxygen utilization and waste production.

Pulse oximetry and End Tidal CO₂ monitoring

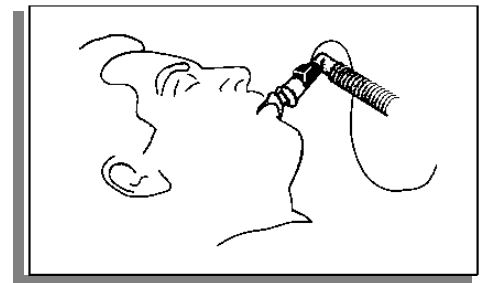
Pulse oximetry

- a pulse oximeter (SpO₂ monitor) is a non-invasive device which measures the amount of oxygen bound to hemoglobin. The device emits red and infrared light through vascular tissue, such as a nailbed, and measures the amounts of absorbed light on the other side.
- because hemoglobin changes its shape depending on whether or not it is carrying oxygen molecules, light absorption also changes depending on whether the hemoglobin is carrying oxygen or not.
- hemoglobin is the oxygen transporting part of the red blood cell
- approximately 98% of oxygen is transported bound to hemoglobin - the remaining 2% is transported dissolved in blood plasma
- each hemoglobin can carry four oxygen molecules
- The blood is said to be fully “saturated” with oxygen if every hemoglobin has bound to it, four oxygen molecules.
- a pulse oximeter measures “saturation” of oxygen bound to hemoglobin by percentage - i.e. if all hemoglobin were carrying four molecules of oxygen each, the saturation would be 100%.
- normal saturation is between 95% and 100%



End Tidal CO₂ or ETCO₂

- the ETCO₂ device measures the amount of exhaled carbon dioxide
- the measurement is taken at the end of exhaled tidal volume; hence “End Tidal CO₂” or ETCO₂ for short.
- measurements taken earlier in the exhalation phase would be misleading, as these gases would include oxygen and traces of other gases.



Oxygenation & Ventilation

They're not the same!

Pulse oximetry and End Tidal CO₂ monitoring are two very valuable adjuncts to prehospital care. However, there are some key respiratory concepts that are essential to review before using these sophisticated, yet simple diagnostic tools.

OXYGENATION

- From a treatment perspective, oxygenation of the patient simply means to provide oxygen. To hyperoxygenate a patient is to provide supplemental oxygen in a high concentration.
- providing supplemental oxygen affects the PaO₂ level (partial pressure exerted by dissolved oxygen in arterial blood plasma). Supplemental O₂ also affects SpO₂ or the amount of oxygen bound to hemoglobin.
- there is a correlation between SpO₂ and PaO₂. That correlation will be described later with the oxyhemoglobin dissociation curve.

Oxygenation - Sequence of events

- When we inhale atmospheric gas, oxygen diffuses across the alveolar-capillary membrane
- it dissolves in blood plasma
- 98% of it is quickly then taken up and bound to hemoglobin, while the rest remains dissolved in plasma
- at the tissue level, oxygen bound to hemoglobin is released, dissolves in plasma, then diffuses into the tissues

VENTILATION

- breathing affects primarily the PaCO₂ level (partial pressure exerted by carbon dioxide in arterial blood plasma) – ETCO₂ is an approximation of PaCO₂
- normal PaCO₂ is 35-45 mmHg
- hyperventilation blows off CO₂ and therefore may result in PaCO₂ (or ETCO₂) level of less than 35 mmHg.
- a patient who is hypoventilating (e.g. narcotic overdose) or a patient who has difficulty exhaling CO₂ because of inflamed bronchioles or mucous plugs in the smaller airways (e.g. emphysemics) will retain CO₂. Consequently, the PaCO₂ (or ETCO₂) level may be above 45 mmHg. This may be a “relative” normal finding for emphysemics. For that reason, emphysemics are sometimes referred to as “CO₂ retainers”.
- In the normal health lung, providing ventilatory support or even hyperventilation (with an FiO₂ of 21%) has little to no effect on PaO₂ or SpO₂, unless supplemental oxygen is added. Hyperventilation does however dramatically lower the ETCO₂ level.

FICK PRINCIPLE

The Fick Principle describes oxygenation from the starting point of oxygen content in the atmosphere (FiO_2) to oxygen utilization at the tissue level.

In the process of troubleshooting why a patient's SpO_2 , consider the following:

Is there?

- **adequate FiO_2 and PAO_2 (atmospheric O_2 in inspired air) ?**
 - patient in a chemical vat where the FiO_2 is less than 21% because oxygen is displaced by other gases
 - the patient is not receiving the high FiO_2 you are trying to deliver because the stretcher wheel is overtop of the oxygen tubing, or the O_2 tank has run dry or has not been turned on.
 - at high altitude there is a lower PAO_2
- **adequate diffusion of O_2 across the alveolar-capillary membrane ?**
 - a shunt, such as exudate from pneumonia, pulmonary edema, bronchospasm and mucous plugs, is impairing gas diffusion and exchange.
- **adequate affinity for O_2 binding ?**
 - in an acidotic state, oxygen doesn't bind as well to hemoglobin
 - in an alkalotic state, oxygen binds very tightly to hemoglobin but does not release easily at the tissue level
 - carbon monoxide (CO) has a greater affinity to hemoglobin than oxygen. Hemoglobin preferentially binds to CO which reduces the oxygen carrying capacity
- **adequate O_2 carrying capacity ?**
 - remember, 98% of oxygen transported in the blood is bound to hemoglobin. A patient who is anaemic or hypovolemic may have an saturation (SpO_2) of 100%, but their oxygen carrying capacity is low. Therefore a patient may be hypoxic despite a normal to high saturation reading.
 - Carbon dioxide (CO) will also bind preferentially to hemoglobin. This not only impairs the body's oxygen carrying capacity, but because a pulse oximeter cannot differentiate between O_2 and CO, you are likely to see a falsely high SpO_2 reading.
- **adequate perfusion ?**
 - shock states or conditions such as a pulmonary embolus reduce or stop blood flow to the lungs resulting in hypoxia
- **adequate release of O_2 at the cellular level ?**
 - a patient may have an SpO_2 of 100%, but if the hemoglobin is not releasing oxygen at the tissue level, hypoxia results. This occurs when blood pH is alkalotic.
- **ability of the cell to utilize the O_2 that is delivered ?**
 - cyanide poisoning prevents the utilization of O_2 at the cellular level. CO, in addition to its affinity for hemoglobin, also impairs the utilization of O_2 at the cellular level.

When you're dealing with a patient who is deteriorating despite your efforts at providing them with supplemental oxygen and/or ventilatory support, let the Fick Principle guide you through your problem solving process.

OXYGEN DELIVERY DEVICES

There are two main categories of patients for which oxygen is administered – those who are spontaneously breathing and can accept free flow oxygen and those who are not breathing or have such a poor ventilatory status that they require assisted ventilation.

There is a wide variety of oxygen delivery systems on the market today and no one device is perfect for every job. Since every device cannot be available at all times, those devices with the broadest spectrum of usage will be discussed in this unit. (It is these devices that are most frequently used by paramedics).

The oxygen delivery systems with the broadest spectrum of usage include:

1. Nasal prongs (cannulae)
2. Non-rebreather mask
3. Aerosol mask
4. Bag-valve-mask

The first three oxygen delivery devices listed above are to be used with spontaneously breathing patients and are considered low flow devices. Low flow devices utilize an oxygen reservoir either located within the device itself or within the body's own anatomic reservoir. Therefore, it should be understood that the system itself does not supply all the inspired gas that a patient requires. Variations in the breathing patterns of the patients can widely affect the FIO_2 (Fraction of Inspired Oxygen)* administered to the patient.

By contrast, high flow systems such as venturi masks are designed to deliver the total gas requirements of the patient while providing a constant and exact FIO_2 . The problem with these devices is that they are generally more expensive and cannot provide as high an FIO_2 as a low flow system.

Although not perfect, the low flow systems seem to have the widest flexibility in prehospital care.



Clinical vignette

In the past there has been concerns over how much oxygen is sufficient and how much is too much. This concern was based on the understanding of the respiratory control centers and the fear of suppressing the hypoxic drive found in patients with chronic obstructive pulmonary disease. However, the chance of this happening in the short time that a paramedic is with a patient is remote. This depression in respiratory drive is more likely to be seen in patients on oxygen for longer periods of time. It is far more dangerous to withhold oxygen from a patient who needs it.

TYPES OF DELIVERY SYSTEMS

NASAL PRONGS

Nasal prongs (cannulae) are effective in patients who do not require greater than 30-40% oxygen. This device utilizes the patient's own anatomical reservoir of oxygen (found in the nasopharynx, oropharynx and hypopharynx) which mixes with the room air entrained with each breath. Oxygen flow rates should never exceed 6 L/min as this would cause rapid drying and dehydration of the nasal mucosa. Flow rates higher than 6 L/min will not cause a significant increase in FIO_2 and therefore result in a waste of oxygen. Patients who will not tolerate a mask may accept nasal cannulae, which may prove to be your only alternative even though a high FIO_2 cannot be obtained.

FIGURE 8: NASAL PRONGS

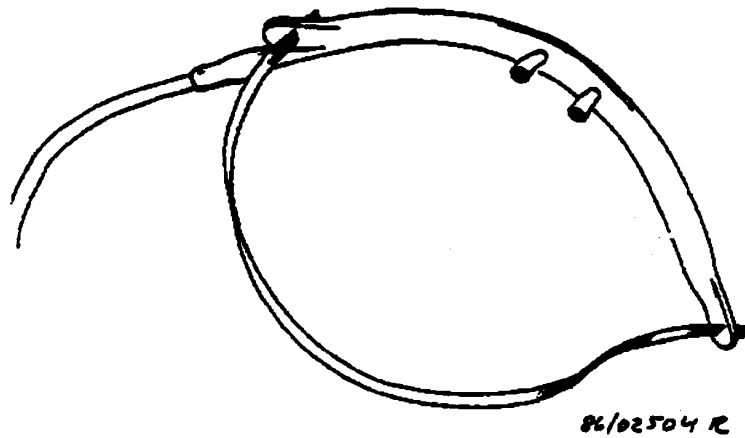


TABLE 2
ESTIMATED NASAL CANNULA FLOW RATES*

<u>FLOW RATE (100% O₂/L)</u>	<u>% OXYGEN CONCENTRATION</u>
1	24%
2	28%
3	32%
4	36%
5	40%
6	44%

* Assuming normal ventilatory effort

NON-REBREATHER (RESERVOIR) MASK

In contrast to the nasal cannulae, the non-rebreather mask utilizes not only the anatomical reservoir but the mask and the reservoir bag that is attached to it. This device is intended to supply high concentrations of oxygen at FIO_2 's between 60-95%. Examples where this device may be utilized include serious trauma, carbon monoxide poisoning, myocardial infarction, pulmonary edema, etc.

Flow rates below 6 L/min should not be used as it may provide insufficient oxygen to fill the reservoir.

FIGURE 9: NON-REBREATHER MASK

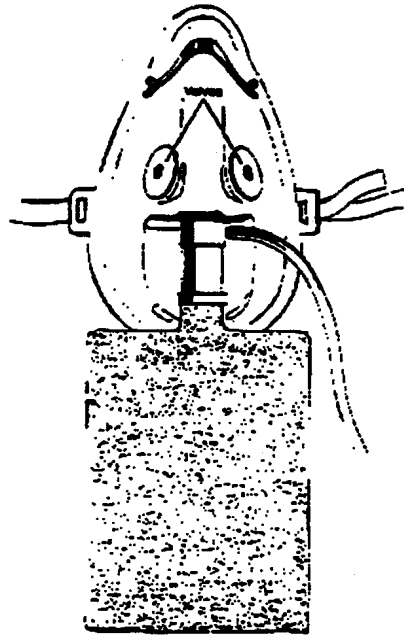


TABLE 3

ESTIMATED NON-REBREATHER FLOW RATES*

<u>FLOW RATE (100% O₂/L)</u>	<u>% OXYGEN CONCENTRATION</u>
6	60%
7	70%
8	80%
9	90%
10	95+%

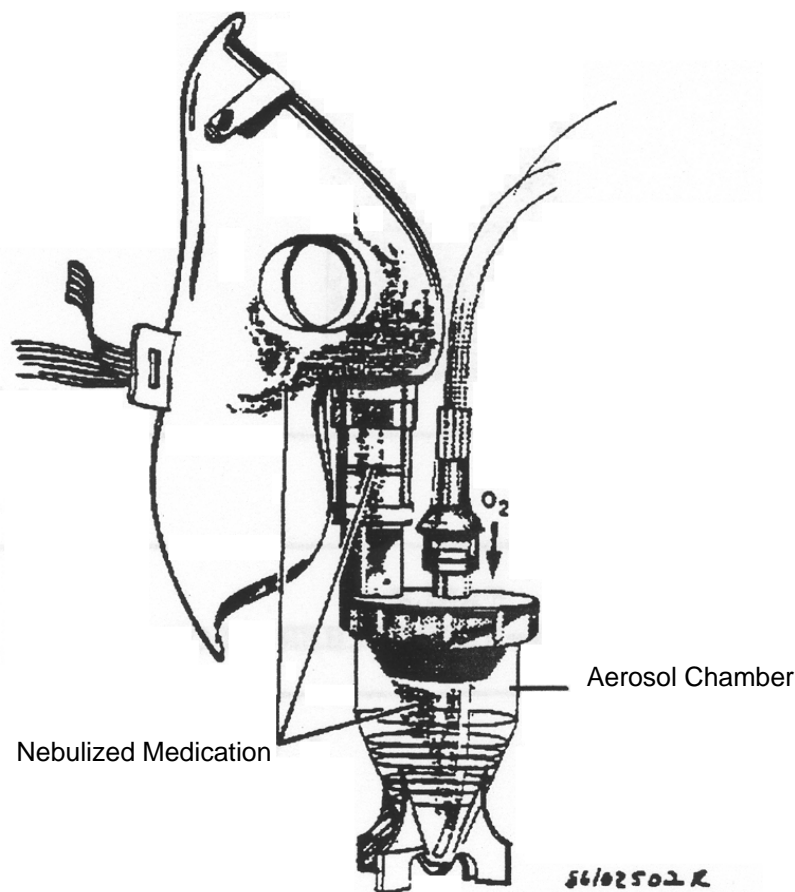
* Assuming normal ventilatory pattern

AEROSOL MASK

The aerosol mask is not something routinely used unless administering medications. The design of this mask is such that the oxygen entrained into it picks up sterile normal saline usually containing a medication, **e.g.** ventolin. As the oxygen passes through the nebulizer it picks up molecular and particulate saline containing medication. This medication is then transferred to the patient via the respiratory system.

At approximately 5-6 L/O₂ this device will provide an FIO₂ of about **40%** oxygen.

FIGURE 10: AEROSOL MASK WITH MINI-NEBULIZER



BAG-VALVE-MASK AND OXYGEN POWERED VENTILATORS

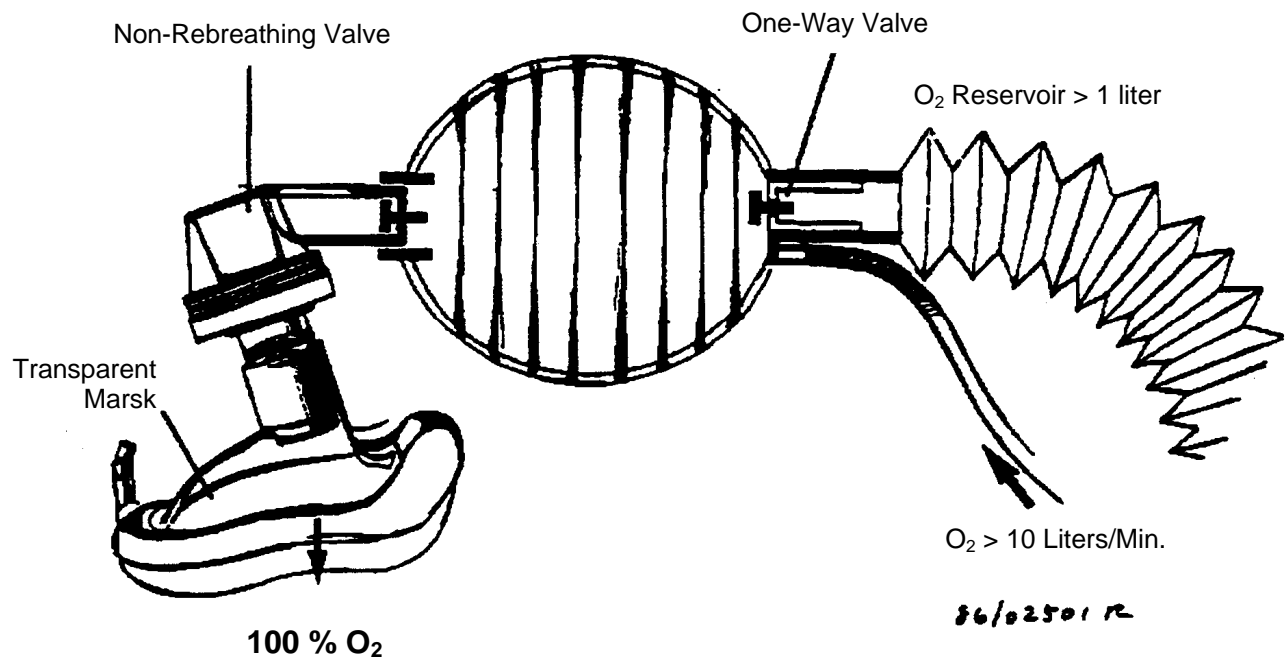
Both of these devices can supply 100% O₂ to a patient by either positive pressure or free flow oxygen. Primarily, they are used to ventilate patients who are either not breathing or have insufficient ventilatory function.

While both will do the job, the O₂ powered ventilators do not allow the operator a feel for the patient's lung compliance. Decreasing compliance is a significant clinical finding. The operator can also feel and hear whether the gas is being delivered to the lungs.

The O₂ powered systems deliver O₂ at a very rapid rate (around 1.6 L/second) and commonly cause an increase in airway pressures. Although most are equipped with a pressure blow off at around 60 cmH₂O gastric distention is common. This is caused by the gastric sphincter muscle in the esophagus having a release point of around 40 cmH₂O. Therefore even with proper use, dangerous and rapid gastric distention may occur causing a decreased in lung volume and an increase potential for vomiting.

The bag-valve-mask system supplies 100% O₂ to the patient when connected to a 15 L/min O₂ source and the reservoir bag is attached. Should the reservoir bag not be used, approximately 60% O₂ can be delivered.

FIGURE 11: BAG-VALVE-MASK



HUMIDIFICATION

Humidification is used to add moisture to the dry oxygen. It is accomplished by bubbling the air through water, thereby increasing the air's relative humidity. Long exposure to very dry air can cause a significant drying of the mucous membranes. The water vapour can also supply warmth to otherwise cool air.



Clinical vignette

In prehospital care, when transport times are under twenty minutes, humidification of oxygen is not as necessary in most cases.

The Ontario Ministry of Health and Long Term Care issued a Directive On May 13, 2003 during the Severe Acute Respiratory Syndrome (SARS) outbreak which stated: "Oxygen should be delivered DRY avoiding nebulized humidity".

Humidified oxygen may increase the risk of transmission of airborne or droplet infection to the health care worker. Follow local and/or provincial Directives.

CALCULATION OF TANK DURATION

To determine the duration or amount of oxygen in a gas cylinder, a formula may be used.

$$\text{Duration of Flow (minutes)} = \frac{\text{Gauge Pressure (psi)} - \text{Safe Residual Pressure (SRP)}}{\text{Flow Rate (L/minute)}}$$

	CONSTANT <u>FACTOR</u>	<u>TANK CAPACITY</u>	GAUGE PRESSURE (<u>FULL</u>)
D cylinder	0.16	350 Litres	2000
E cylinder	0.28	625 Litres	2000
M cylinder	1.56	3000 Litres	2000

The safe residual pressure for all oxygen tanks is 200 psi.

EXAMPLE 3:

What is the duration of tank M, when using a flow rate of 10 L/minute?

$$\begin{aligned}\text{Duration of Flow} &= \frac{2000 - 200}{10} \times 1.56 \\ &= \frac{2808}{10} \\ &= 281 \text{ minutes} \\ &\quad (4 \text{ hours, } 41 \text{ minutes})\end{aligned}$$

Clinical Note

A HYPOXIC PATIENT SHOULD NOT HAVE OXYGEN WITHHELD FOR ANY REASON

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SELF-ASSESSMENT

Marks

- [1] 1. a) What is meant by “partial pressure” of a gas?
b) The total pressure of the three gases (A, B, C) in the boxes are equal to 760 mmHg. What is the partial pressure of each gas?

A	B	B	A	C
B	C	B	C	A

GAS A: _____ mmHg

GAS B: _____ mmHg

GAS B: _____ mmHg

- [2] 2. Given an adequate supply of oxygen within the alveoli, identify the factors which determine the quantity of oxygen delivered to the tissues.

- [1] 3. Oxygen moves out of the alveoli into the circulation by the process of (a) _____.

- [2] It is transported in the circulation primarily by (b) _____, and minimally by (c) _____.

- [1] Oxygen release to the tissues occurs when (d) _____.

- [3] Factors which effect oxygen release to tissues are (e) _____.

- [3] 4. List, in order of quantity (largest to smallest), the means by which carbon dioxide is transported in the body.

- [1] 5. a) The major types of hypoxia are:

[1] b) Cardiogenic shock is an example of which type of hypoxia?

[1] 6. The most reliable indication of hypoxia is cyanosis. (True or False)

[2] Explain your answer.

7. a) Using the chart below, identify the chemical factors which affect ventilation, the site affected, and the effect on ventilation.

		RESULT OF INCREASE IN FACTOR ON VENTILATION (↑ OR ↓)
FACTOR	SITE AFFECTED	

[1] b) The two factors which act together in the control of ventilation are:

[1] c) The least control is exerted by the level of _____ in the blood.

[1] 8. a) Assuming a normal ventilatory pattern, the nasal cannula will provide _____ % oxygen concentration at a flow rate of 3 L/min.

[1] b) Room air is _____ % oxygen.

[4] 9. An otherwise healthy young man is having an acute attack of asthma. The physician has ordered an inhalation treatment using the aerosol mask and mini nebulizer. The medication in the chamber is now gone. The patient appears slightly better. Your ETA to hospital is 15 minutes.

In the absence of a direct order from the physician re: oxygen administration following the inhalation, choose the best option below.

[3] Justify your answer explaining briefly why you did not choose the other options.

- a) Leave the aerosol mask in place, with O₂ running.
- b) Switch to nasal prongs at 6 L/min.
- c) Fill the nebulizer chamber with water and allow the patient to breathe humidified oxygen.
- d) Switch to non-rebreather mask at 8-10 L/min.

[2] 10. You are called to transfer a patient from hospital A to hospital B. The transport time will be 60 minutes. The doctor orders oxygen at 4 L/min via nasal cannulae during transport. You have a full (2000 psi) D tank ready for the journey. Calculate the number of minutes this tank will last.

33 TOTAL

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SELF-ASSESSMENT ANSWERS

1.
 - a) The weight, force or tension exerted by a gas within a mixture.
 - b) The partial pressure of each gas is calculated as a percentage of the whole.
GAS A: 30% of 760 = 228 mmHg
GAS B: 40% of 760 = 304 mmHg
GAS B: 30% of 760 = 228 mmHg
2. Blood flow (perfusion)
The concentration of hemoglobin and the affinity of oxygen for it (oxygenation).
3.
 - a) diffusion
 - b) combining with hemoglobin
 - c) dissolving in plasma
 - d) oxygen concentration in tissues is lower than in the blood
 - e) pH, temperature, PCO₂
4. as bicarbonate – largest hypoxia
combined with hemoglobin (carbaminohemoglobin)
dissolved in plasma - smallest
5.
 - a) hypoxemia; tissue hypoxia
 - b) tissue hypoxia due to a lack of perfusion
6. False. Cyanosis will be reduced or absent in patients with carbon monoxide poisoning, and those with decreased hemoglobin levels.

Other factors such as cold temperatures can reduce peripheral perfusion resulting in cyanosis. There is no reliable way to quantify cyanosis clinically. Therefore, as an isolated clinical finding it has little relevance to the patient's PO₂.

7. a) 1/3 mark each

FACTOR	SITE AFFECTED	RESULT OF INCREASE IN FACTOR ON VENTILATION (↑ OR ↓)
↑ CO ₂	Central chemoreceptors (medulla)	↑
↓ pH ↑ (H ⁺)	Central chemoreceptors (medulla)	↑
↓ O ₂	Pheripheral chemoreceptors (cartoid plus aortic)	↑

b) CO₂ + pH (H⁺)

c) O₂

8. a) 32%

b) 21%

9. (d)

Rationale: There is no good reason not to give this patient the highest concentration of oxygen available. The non-rebreather mask at 8-10 L/min delivers 80-95% oxygen concentration. The nasal cannulae deliver about 44% at 6 L/min., and the aerosol mask about 40% oxygen concentration. Humidification in a trip lasting 15 minutes is not necessary, especially when the O₂ concentration delivered is only 40%.

10. $\frac{2000 - 200 \times 0.16}{4} = \frac{288}{4} = 72$ minutes of oxygen

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EVALUATION

Upon completion of this module, please fill in and return this form to your base hospital co-ordinator.

Your comments will help to ensure that this unit is a useful learning module. Please indicate any problems that you may have encountered. All suggestions for improvement are welcomed.

1. How long did it take to complete this module? Please estimate.

Reading	_____	hours
Self assessment	_____	hours
Total time	_____	hours

2. Were the objectives of the module clearly stated?

yes no
If no, please comment.

3. Did you see any of the resource materials?

yes no
If yes, which items

Were they helpful? _____

4. Were the reference notes adequate?

yes no
If no, please comment.

5. Were the reference notes easy to follow?

yes no
If no, please comment.

6. Were the examples provided satisfactory?

yes no
If no, please comment.

7. Were any of the self-assessment questions poorly worded?

yes no
If yes, please specify.

1. Was the level of the module satisfactory for your program of study?

yes no
If no, please comment.

Base Hospital _____

9. General comments or suggested improvements.