# Effects of low and high gas pressure on the body

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# Objectives

**By the end of this lecture you should be able to:**

1-Describe the effects of exposure to low and high barometric pressures on the body.

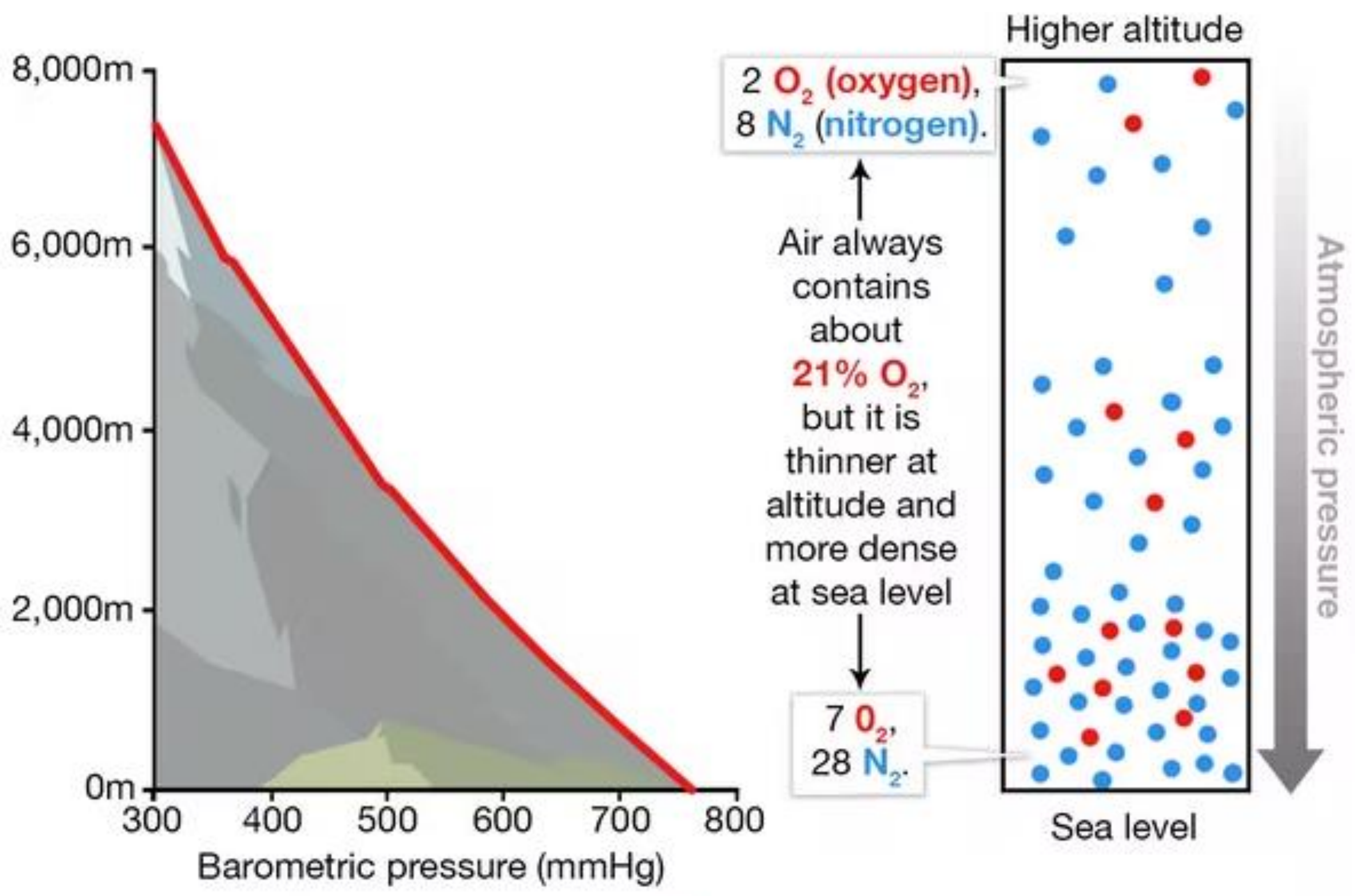
2- Describe the body acclimatization to low barometric pressure.

3-Define decompression sickness and explain how it can be avoided.

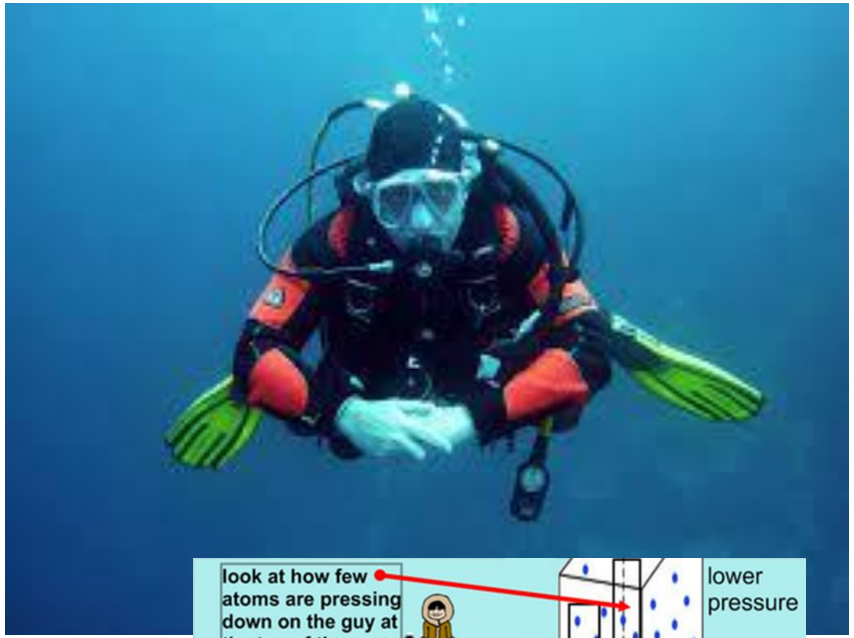
4-Understand the effects of high nitrogen pressure, and nitrogen narcosis.

5- Describe the acute and chronic mountain sickness.

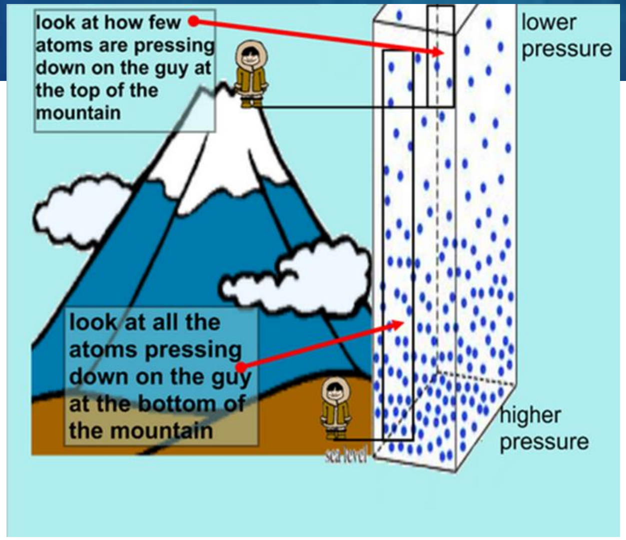
# The impact of altitude on oxygen level



# Effect of increased barometric pressure (Deep sea diving)



- When human descend below the sea, the pressure around them increased.
- To prevent the lungs from collapse air must be supplied also under high pressure.
- This exposes the blood in the lungs to extremely high alveolar gas pressure (hyper-barism).
- Under certain limits these high pressures cause tremendous alterations in the physiology of the body.



# SCUBA Apparatus

- The scuba, or self- contained underwater breathing apparatus, used by recreational, scientific, commercial, and military divers.
- It permits divers to move independently under water.
- This system consists of the following components:

  (1) one or more tanks of compressed air.

  (2) A first-stage "reducing" valve for reducing the very high pressure from the tanks to a low pressure level.

  (3) A combination inhalation "demand" valve and exhalation valve

  (4) A mask and tube system with small "dead space."

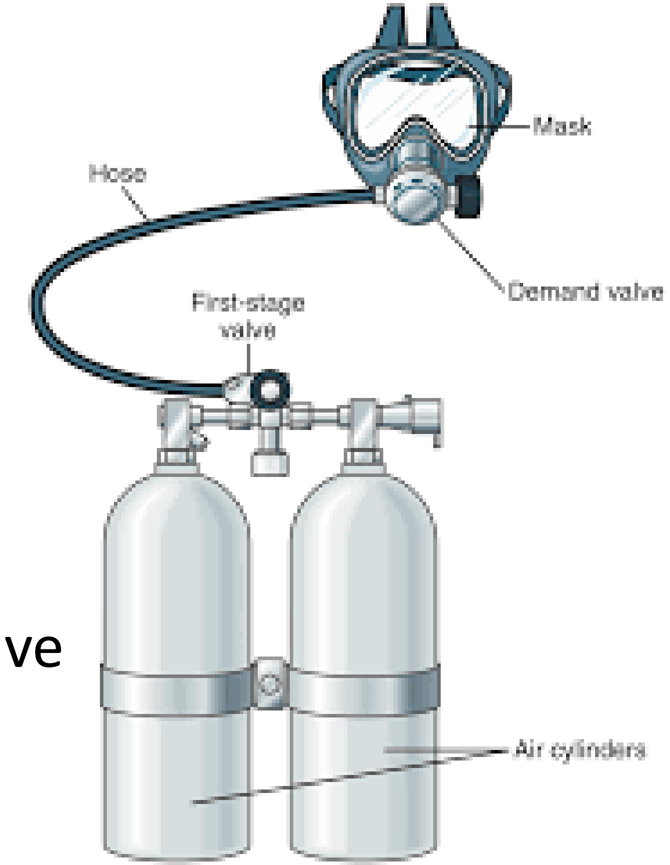
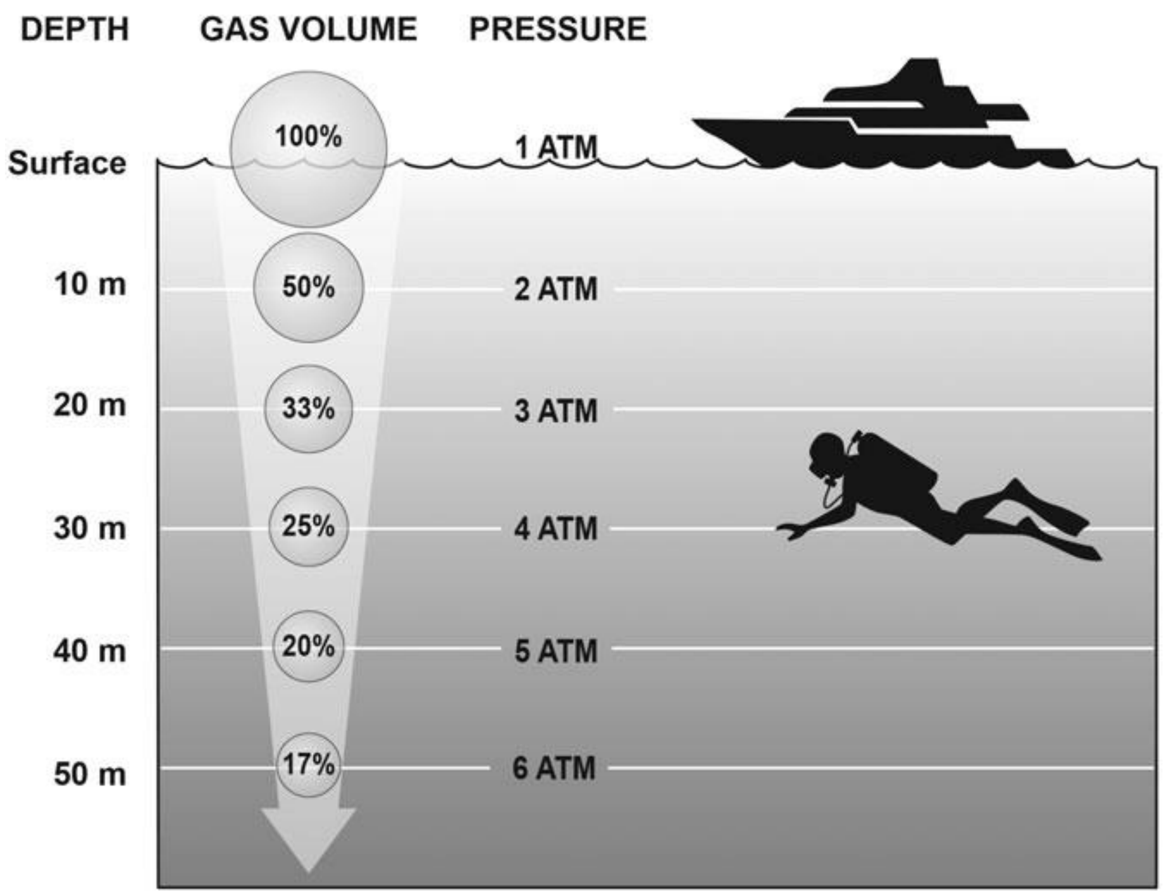



Figure 45-4. Open-circuit demand type of SCUBA.

# Cont. Effect of increased barometric pressure

- The surrounding pressure increases by 1 atmosphere for every 10 meter (33 feet) of depth in sea water. So the diver is exposed to 2 atmospheric pressures.
- Therefore at a depth of 31 meter (100 feet) in the ocean the diver is exposed to a pressure of 4 atmospheres.
- These problems confront SCUBA.



# Effect of increased barometric pressure

➢ **Effect of depth on the volume of the gases:**

At depth there is compression of gases to smaller and smaller volumes. i.e 1L (sea level )→1/2 L at 33 feet and so on.

➢ **Effect of depth on density of gases:**

There is increase in the density of gas and hence increased work of breathing.

➢ **Nitrogen effect at high nitrogen pressure:**

Nitrogen will has 2 principle effects:

* Nitrogen narcosis (anesthetic effect).

* Decompression sickness.

| Depth (feet) | Atmosphere(s) |
| --- | --- |
| Sea level | 1 |
| 33 | 2 |
| 66 | 3 |
| 100 | 4 |
| 133 | 5 |
| 166 | 6 |
| 200 | 7 |
| 300 | 10 |
| 400 | 13 |
| 500 | 16 |

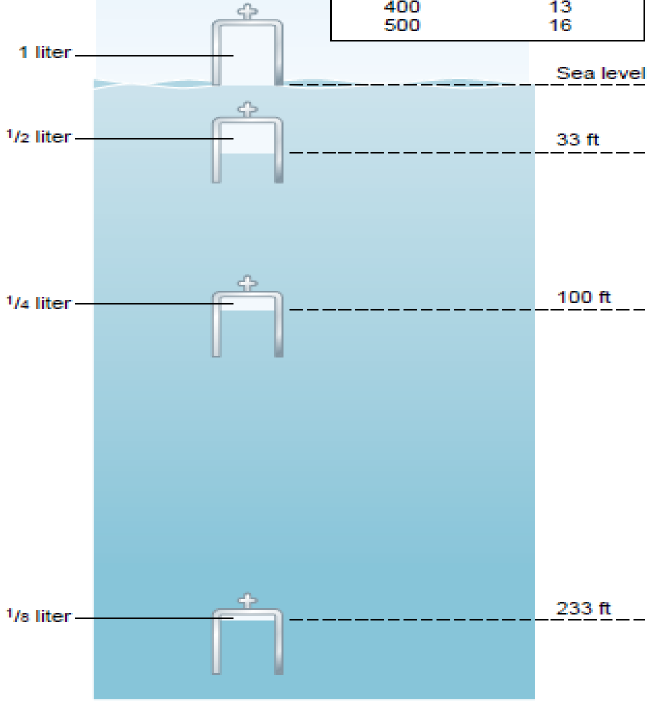



**Figure 44–1**

Effect of sea depth on pressure (*top table*) and on gas volume (*bottom*).

# Oxygen toxicity when breathing hyperbaric air ( effect of very high PO2 on blood oxygen transport)

- When the PO2 in the blood rises above 100 mmHg, the amount of oxygen dissolved in the water of the blood increases markedly.
- **Acute Oxygen Poisoning.** The extremely high tissue PO2 that occurs when oxygen is breathed at very high alveolar oxygen pressure can be detrimental to many of the body's tissues.
- At 4 atmospheres pressure of oxygen (PO2 = 3040 mm Hg) will cause brain seizures followed by coma in most people within 30 to 60 minutes.
- Other symptoms include nausea, muscle twitching, dizziness, disturbances of vision, irritability, and disorientation.

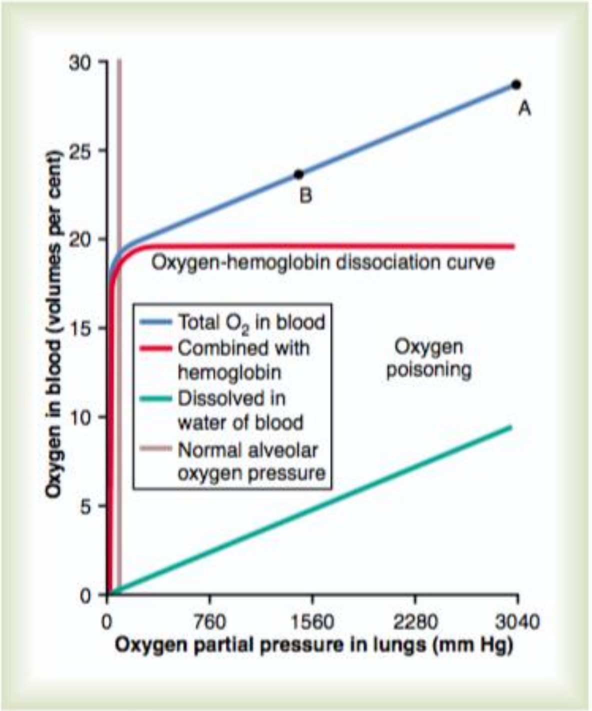
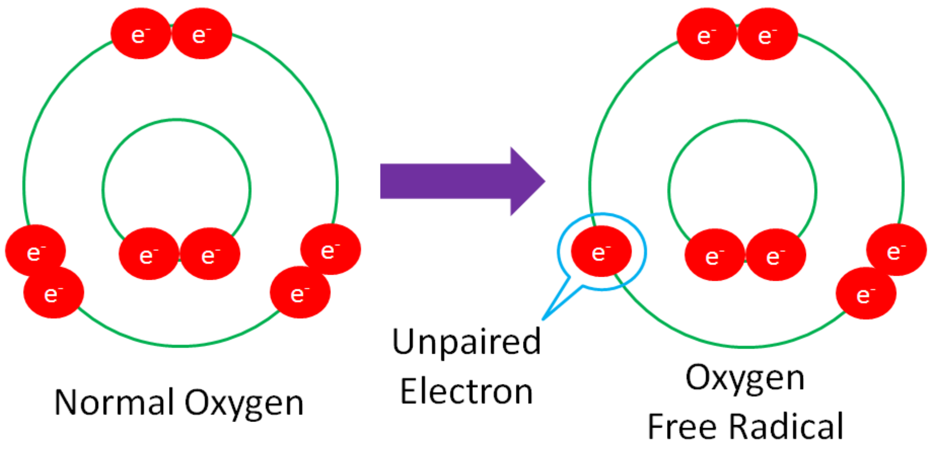



**Figure 44–2**

Quantity of oxygen dissolved in the fluid of the blood and in combination with hemoglobin at very high $Po_2$s.

# Cont. Oxygen toxicity at a high PO2

- Molecular oxygen ($O_2$) has little capability of oxidizing other chemical compounds. Instead, it must first be converted into an "active" form of oxygen called oxygen free radicals. e,g superoxide and hydrogen peroxide.
- At high levels, these oxygen free radicals can have serious destructive and even lethal effects on the cells.

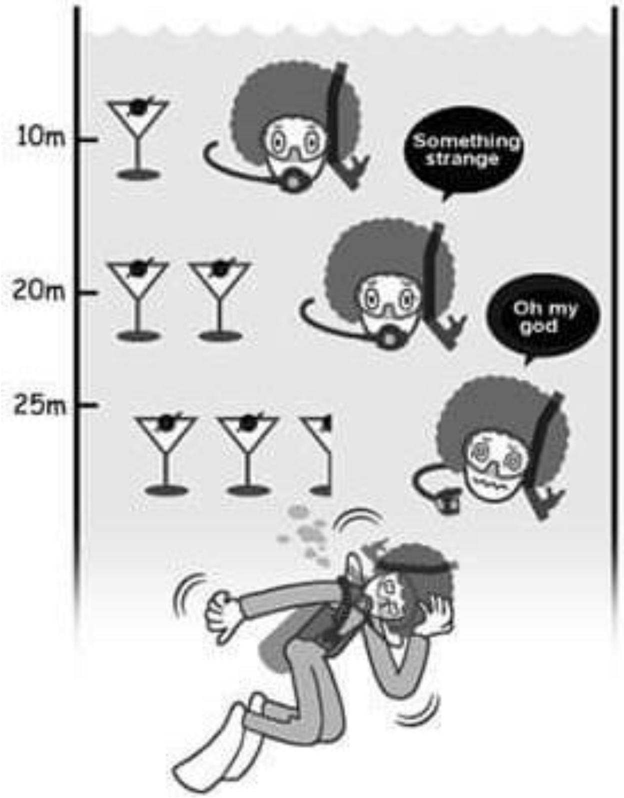


# Nitrogen narcosis

- Nitrogen like most other anesthetic gases, dissolve freely in the fats of the body including the membranes and other lipid structures of the neurons.
- This leads to alteration of the electrical conductance of the membranes, reduces their excitability and subsequent narcosis develops.
- **At 120 feet:** the diver start to have changes in consciousness.
- **At 150 feet:** there is a feeling of euphoria and drowsiness and impaired performance.
- **At higher pressure:** loss of coordination and finally coma might develop.

| Feet | Liters |
|---|---|
| 0 | 1 |
| 33 | 2 |
| 100 | 4 |
| 200 | 7 |
| 300 | 10 |

Volume of Nitrogen Dissolved in the Body Fluids at Different Depths.



# Decompression Sickness ( the Bends, Compressed Air Sickness, Caisson Disease, Diver's Paralysis, Dysbarism).

- It is a syndrome caused by a decrease in the ambient pressure which occur in animal and human when the tissues of the body contain an excess of physically inert gas.
- During descent, the high partial pressure of nitrogen (encountered when breathing compressed air at depth) forces this gas into solution in body tissue particularly in fat (it has a high N2 solubility).
- On ascending, this inert gas comes out of physical solution forming a gaseous phase (bubbles), leading to symptoms and signs.

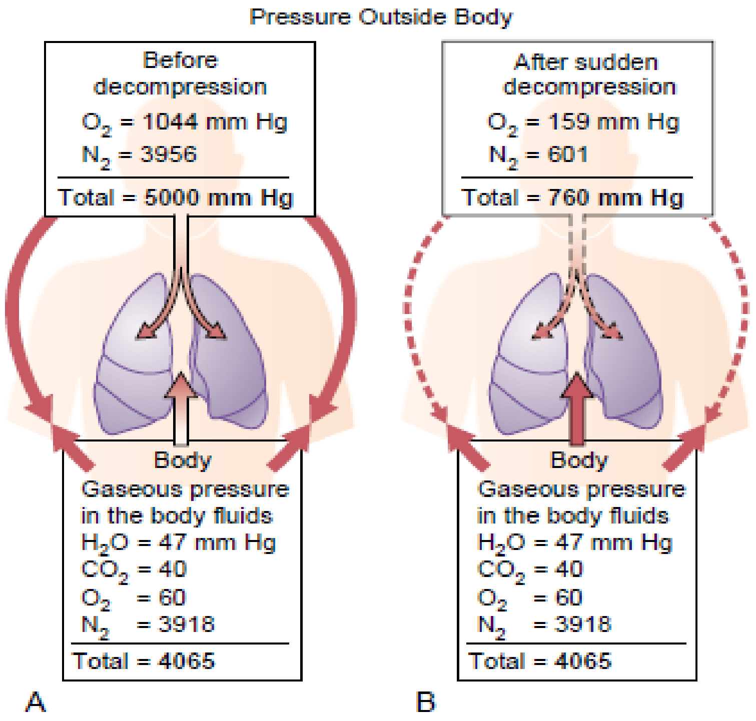
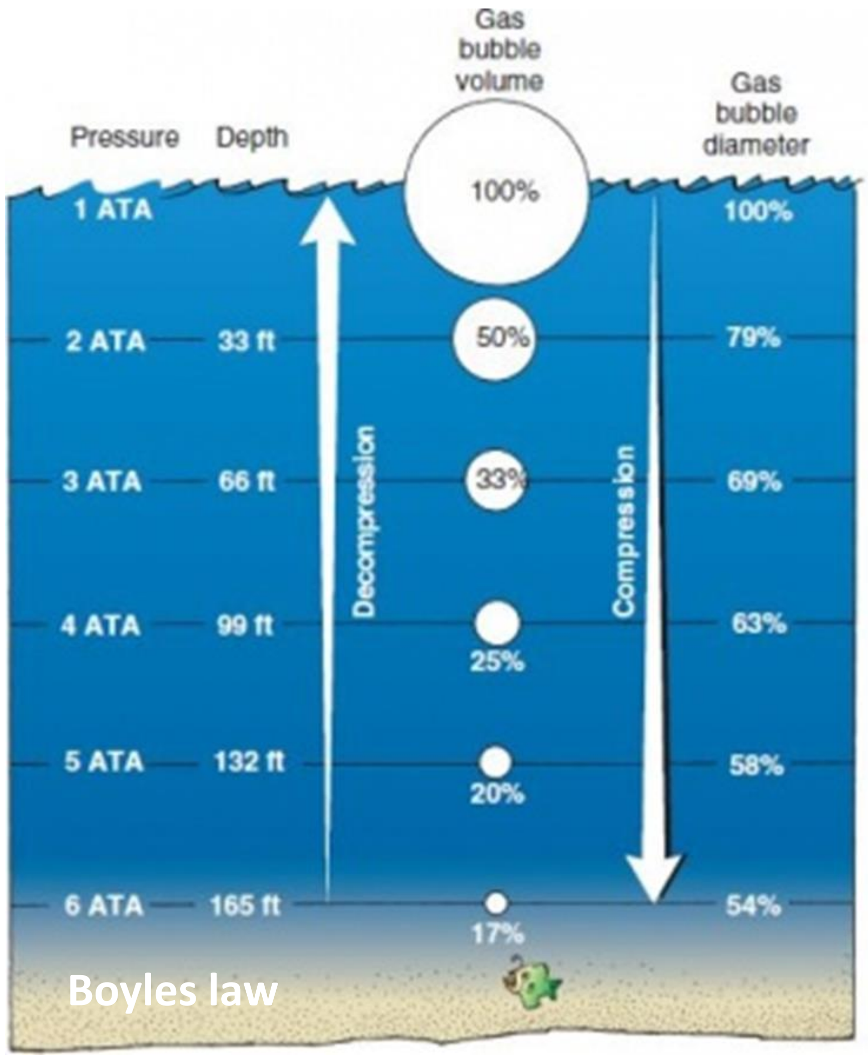



**Figure 44–3**

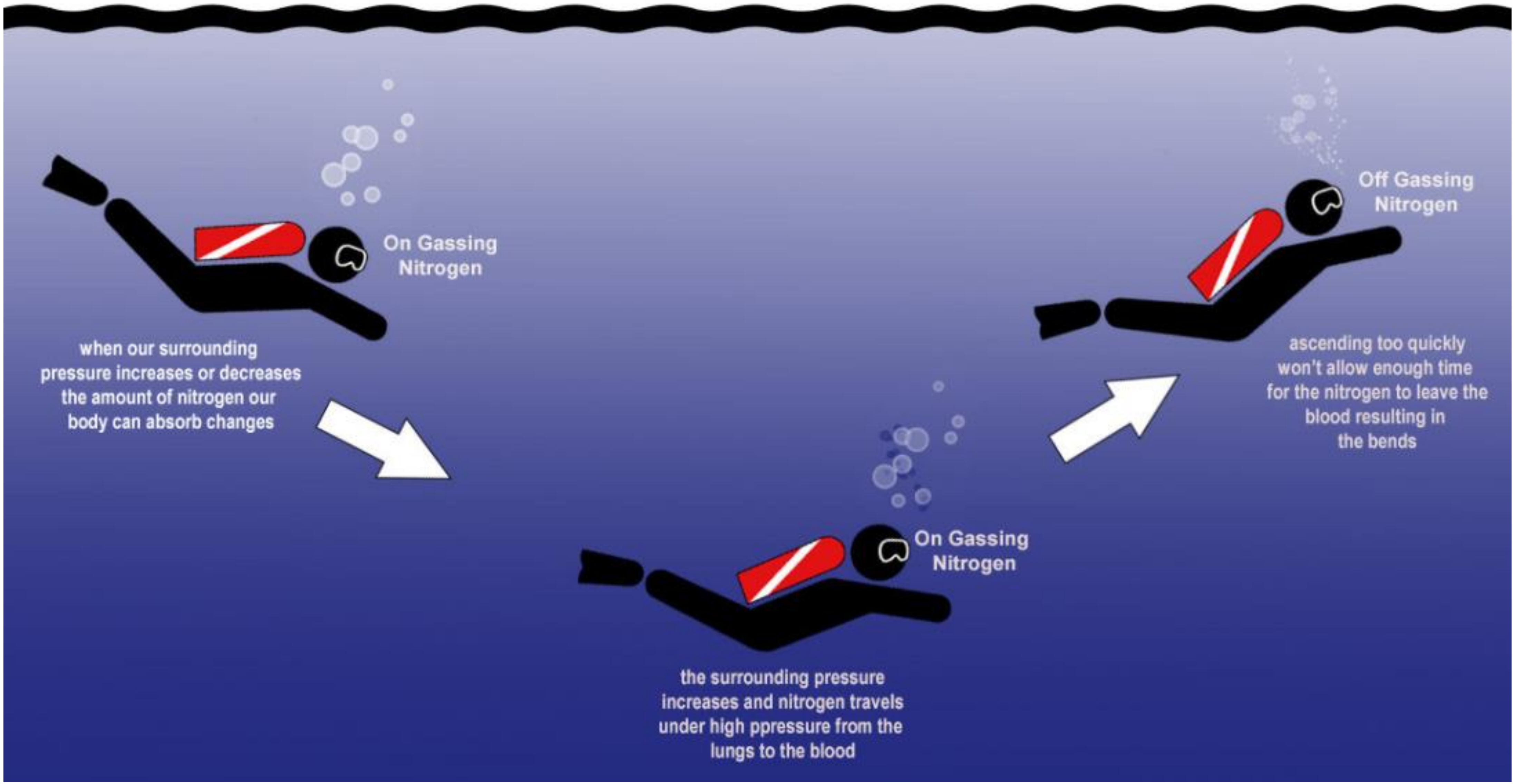
Gaseous pressures both inside and outside the body, showing (*A*) saturation of the body to high gas pressures when breathing air at a total pressure of 5000 mm Hg, and (*B*) the great excesses of intra-body pressures that are responsible for bubble formation in the tissues when the lung intra-alveolar pressure body is suddenly returned from 5000 mm Hg to normal pressure of 760 mm Hg.

# Laws behind decompression sickness

- Pascals Law applies to the diving body (without air filled areas such as lungs) states that the pressure applied to any part of the enclosed liquid will be transmitted equally in all directions through the liquid.
- Boyles Law applies to the diving body's air filled areas such as lungs, sinuses, middle ear, and states that the volume and pressure of a gas at a given temperature are inversely related.



# Decompression sickness



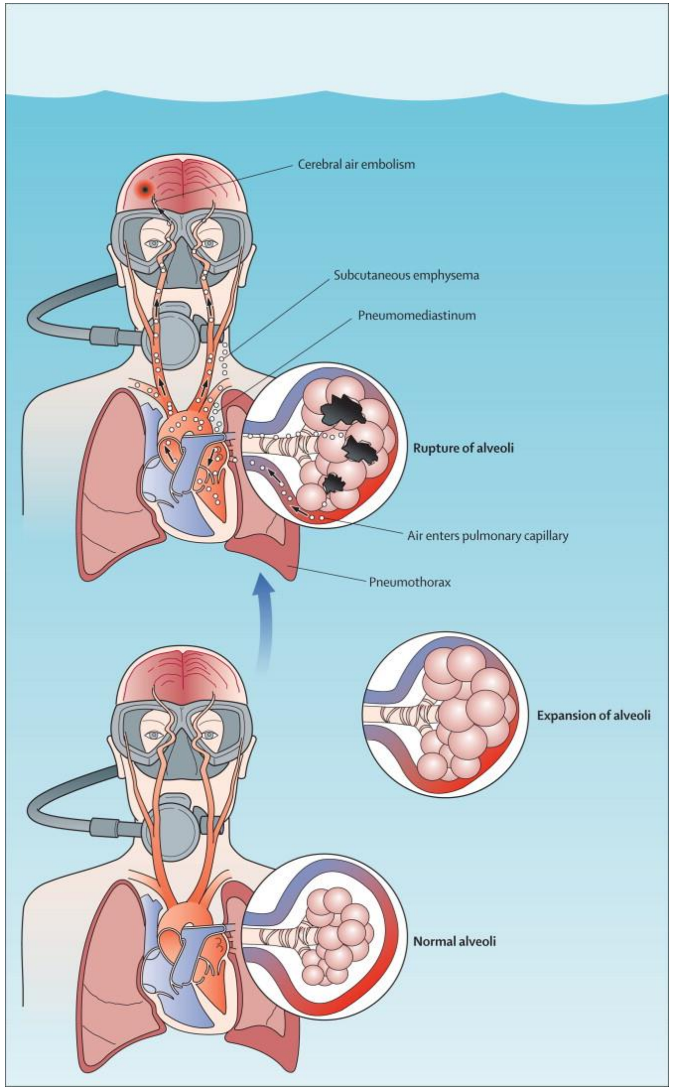
# Cont.. Decompression sickness

- **During slow ascent:**

  N2 is slowly removed from the tissues since the partial pressure there is higher than that in the arterial blood and alveolar gas.

- **If decompression is rapid**:

  bubbles of gaseous nitrogen are released, in tissues and blood, causing the symptoms of decompression sickness (the bends or caisson disease).



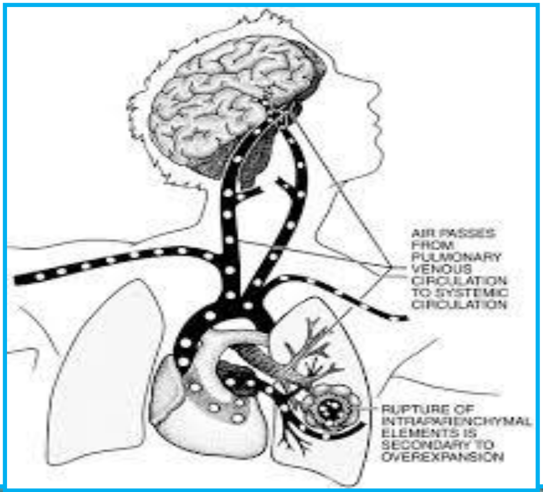
# Symptoms and signs of decompression sickness (DS)

- **The mildest form of DS** is fatigue or drowsiness after decompression.
- **Locally** there is skin itch
- **Other sever symptoms may occur e.g.:**

- **bubbles in the tissues** cause sever pains particularly around the joints.
- **Neurological symptoms** include paresthesia, itching, paralysis, and inner ear disturbances.

# Cont.. decompression sickness

- Thoracic pains: dyspnea, substernal pain, cyanosis, and cough.
- Bubbles in the coronary arteries may cause myocardial damage.
- Decompression sickness shock, capillaries become permeable to plasma and hypovolemia rapidly develops.
- Edema may be prominent and shock is also usually complicated by pulmonary edema..




# Types of decompression sickness

**Type I (Pain only DCS)**

- Involves the joints and extremities, with constitutional symptoms
- Usually only single joint is involved, most commonly:
  - Shoulder
  - Elbow
  - Knee
- Skin and lymphatics
  - Pruritus, stinging, paresthesias, hot/cold sensations
  - Fine scarletiniform rash from nitrogen movement through sweat glands
  - Cutis marmorata - marbling rash, purplish-bluish discoloration.
  - Pitting edema, peripheral swelling from lymphatic blockage

# Cont…Types of decompression sickness

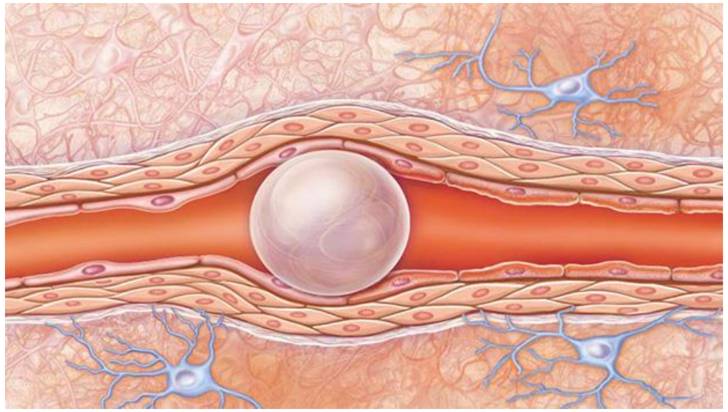
**Type II (Serious DCS)**

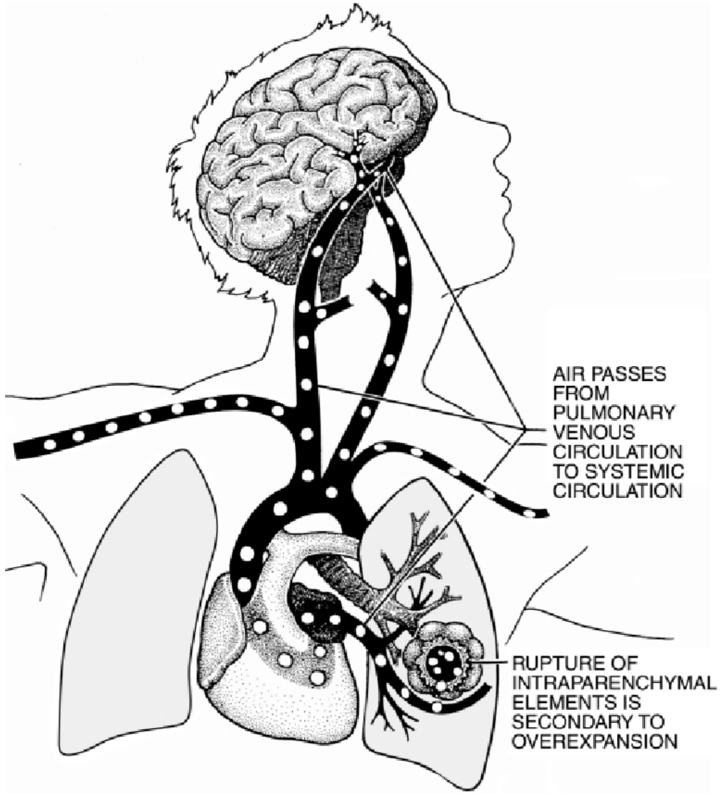
- Some consider multiple joint involvement qualifies as Type II
- Spinal cord involvement:
  - Ascending paralysis
  - Signs often cannot be traced to single location in the cord (may have skip lesions)
    - Limb weakness, paresthesias, or paralysis.
    - Urinary retention, fecal incontinence, or priapism.
- Vestibular ("staggers") involvement:
  - Vertigo, hearing loss, tinnitus.
    - Differentiated from inner ear barotrauma which usually occurs on descent.
- Pulmonary "chokes"
  - Cough, hemoptysis, dyspnea, substernal chest pain.

# Cont….Types of decompression sickness

**Type III (Type II + gas embolism)**

- Variety of stroke symptoms/signs.
- May spontaneously resolve.





# Treatment of decompression symptoms (DS)

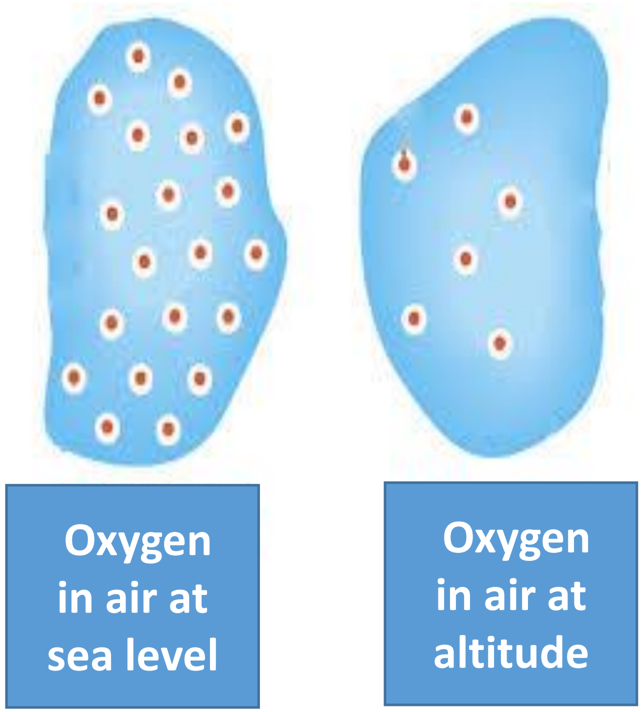
- Rapid recompression in a pressure chamber followed by slower decompression.
- This reduces the volume of the bubbles and forces them back into solution.
- In a very deep dives, the risk of decompression sickness can be reduced if a helium-O2 mixture is breathed during the dive.
- **Also it is important to reduce the oxygen concentration in the gaseous mixture to avoid oxygen toxicity that would cause seizures .**

# Cont.. Treatment of decompression sickness (DS)

- **Helium is more desirable than nitrogen in deep dives because it has:**
  - 1/4 - 1/5 the narcotic effect of nitrogen on CNS.
  - 1/7 the molecular weight of nitrogen.
  - Low density leading to decreased air way resistance of diver.
  - Helium is about 1/2 as soluble as nitrogen in body fluids. This reduces the quantity of bubbles that can form in tissues when the diver is decompressed after diving.
  - Diffuses out of the tissues during decompression several times as rapidly as does nitrogen, thus reducing the problem of decompression sickness.

# Effects of low oxygen pressure on the body ( Aviation-ascend to high altitude)

- At the sea level the barometric pressure is 760 mmHg.
- At 10,000 feet above sea level it is 523 mmHg
- At 50,000 feet 87 mmHg.
- This decrease in barometric pressure is the basic cause of all the hypoxia problems in high altitude in physiology.




# Alveolar PO2 at different altitudes

- As the barometric pressure decreases, the oxygen partial pressure decreases proportionally, remaining less than 21 % of the total barometric pressure.
- At sea level PO2= 159 mmHg.
- At 20,000 feet PO2= 40 mmHg.
- At 50,000 feet PO2= only 18 mmHg.

•Even at high altitude CO2 is continuously excreted from the pulmonary blood into the alveoli. Also, water vaporizes into the inspired air from the respiratory surfaces.

•Therefore, these two gases dilute the oxygen in the alveoli, thus reducing the oxygen concentration and therefore hypoxia develops.

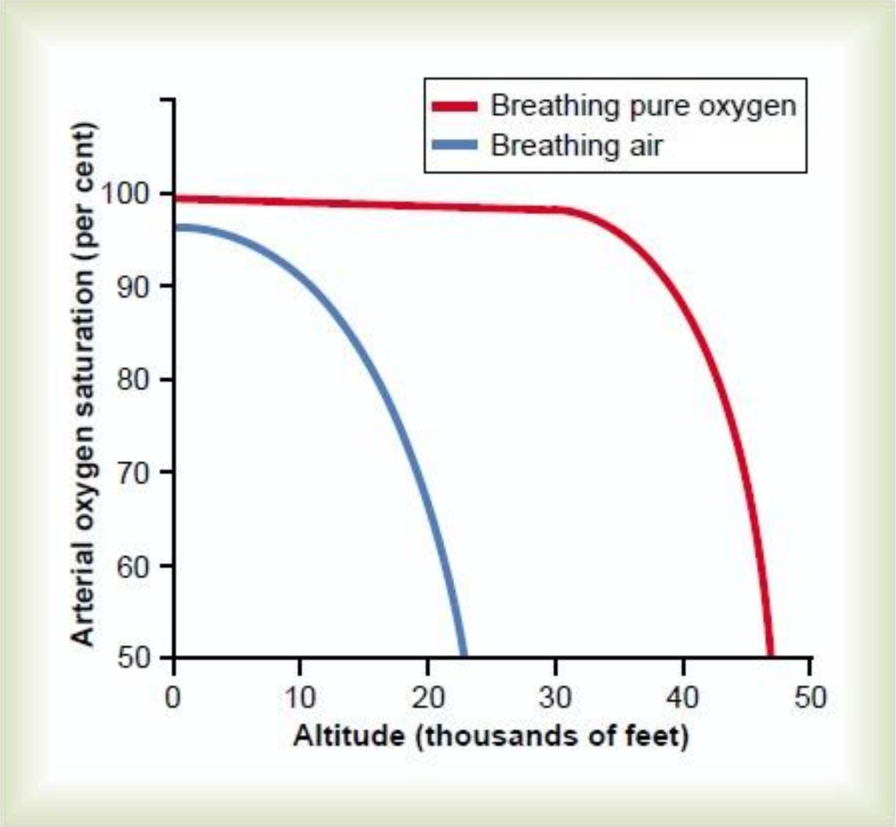
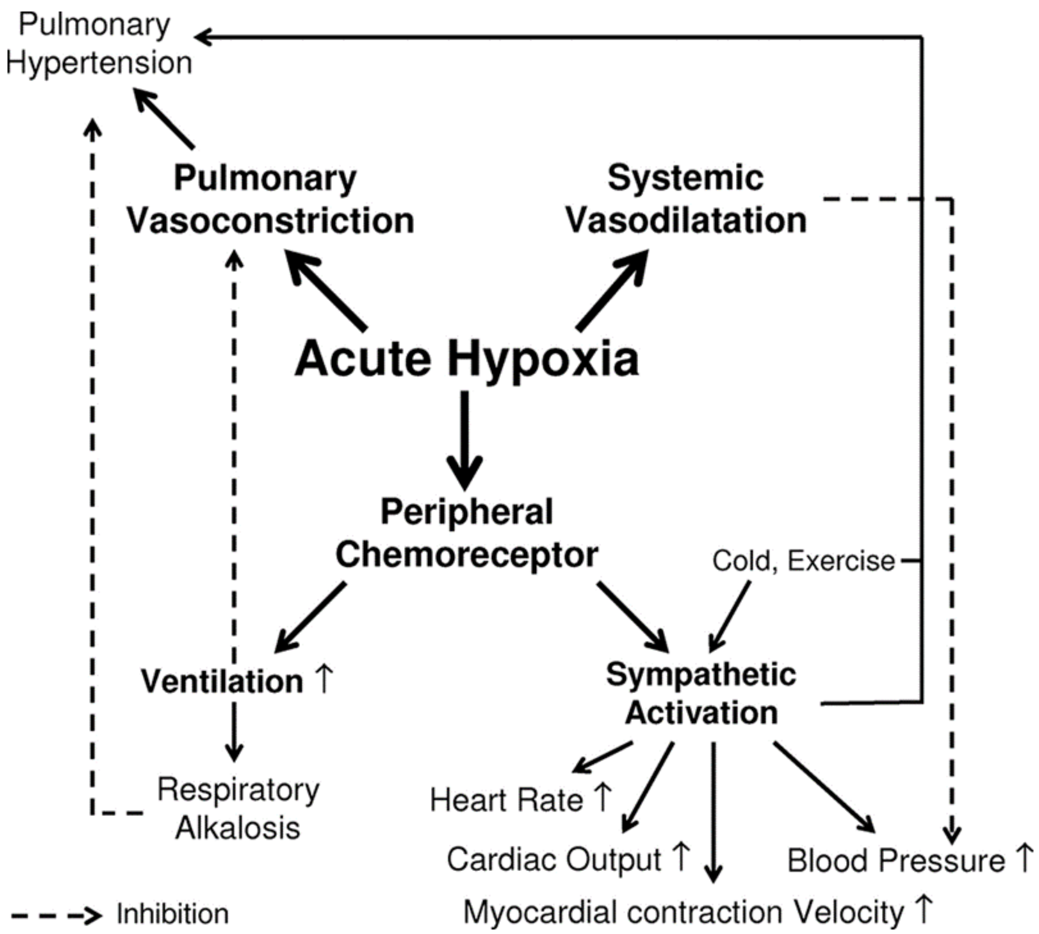



Figure 43–1

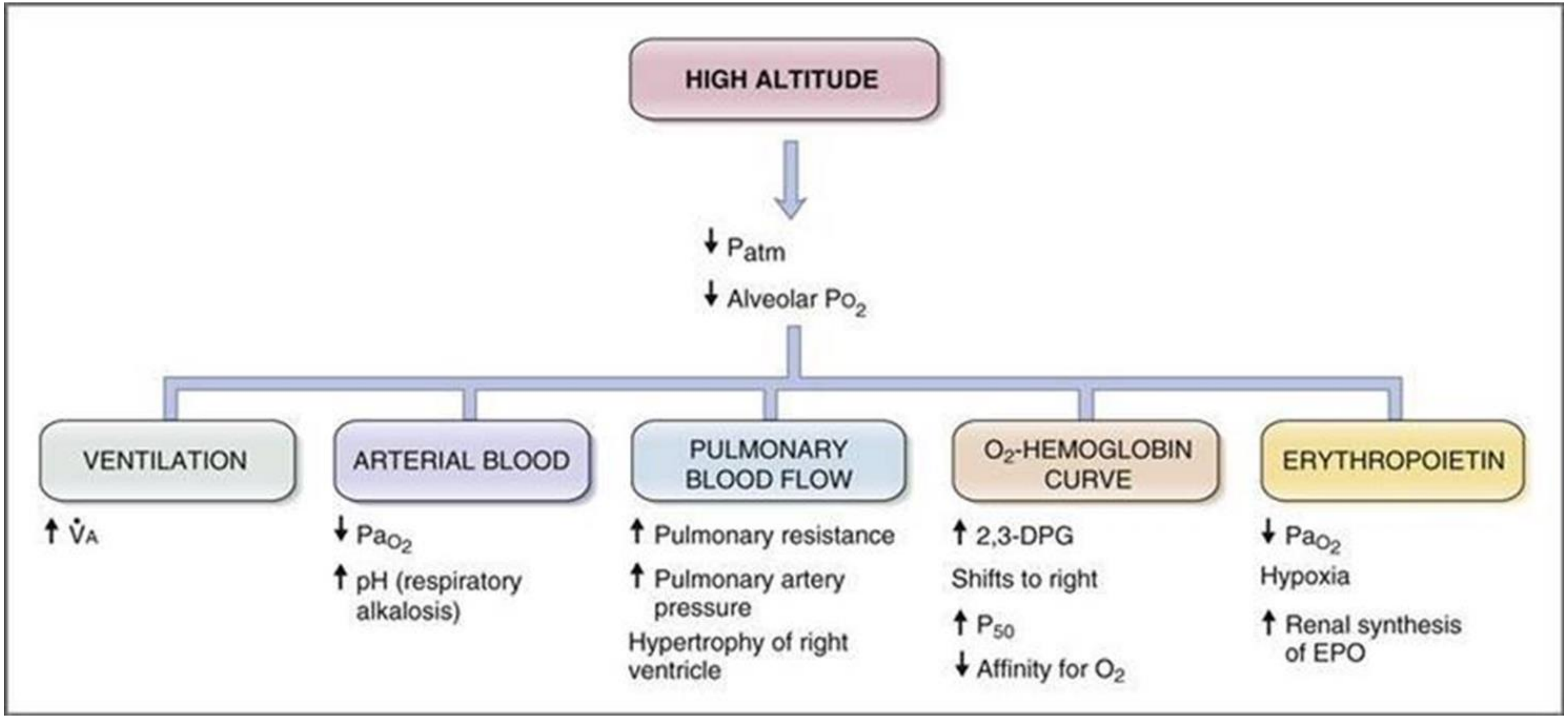
Effect of high altitude on arterial oxygen saturation when breathing air and when breathing pure oxygen.

# Effects of acute hypoxia

- Some of the important acute effects of hypoxia beginning at an altitude of approximately 12,000 feet, are:
- Drowsiness, lassitude, mental and muscle fatigue, sometimes headache, occasionally nausea and sometimes euphoria.
- All these progress to a stage of twitching or convulsions above 18,000.
- Above 23,000 feet the un acclimatized person can enter into coma.



# Physiological response to high altitude



# Acclimatization to low PO2

- A person remaining at high altitudes for days , weeks or years becomes more and more acclimatized to low PO2.
- So that it causes fewer deleterious effects on the body and it becomes possible for the person to work harder without hypoxic effects or to ascend to still higher altitude.

**Acclimatization means the process or result of becoming accustomed to a new climate or to new conditions.**

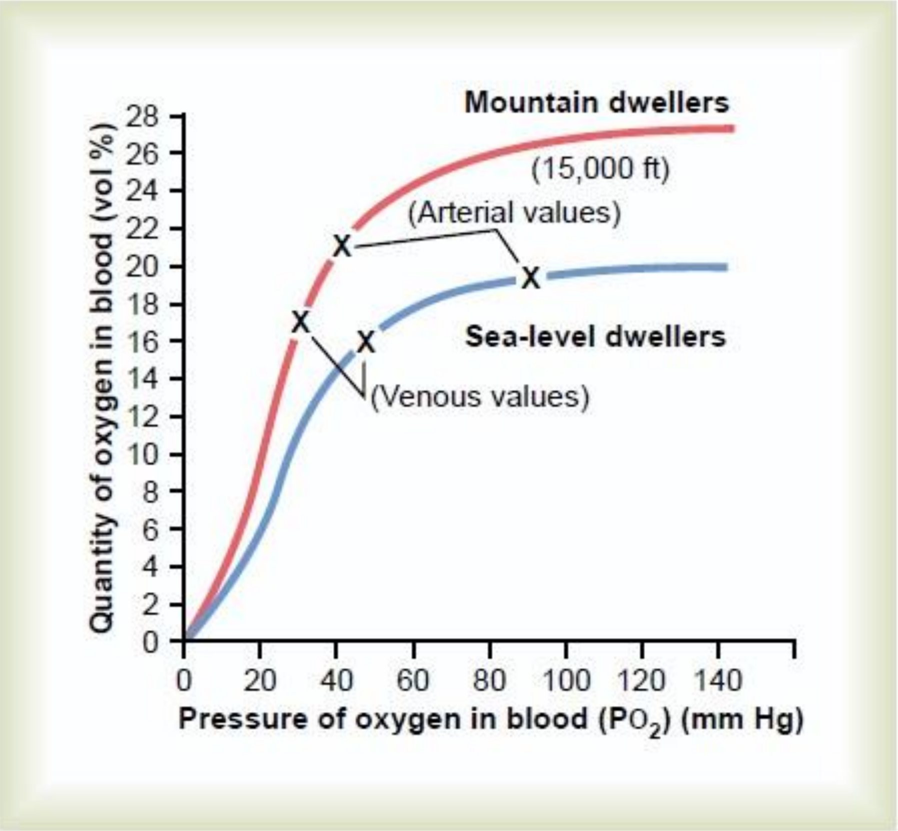



**Figure 43–2**

Oxygen-hemoglobin dissociation curves for blood of high-altitude residents (*red curve*) and sea-level residents (*blue curve*), showing the respective arterial and venous $PO_2$ levels and oxygen contents as recorded in their native surroundings. (Data from Oxygen-dissociation curves for bloods of high-altitude and sea-level residents. PAHO Scientific Publication No. 140, Life at High Altitudes, 1966.)

# Principle means of acclimatization

1- Increase in pulmonary ventilation.

2- Increased red blood cells.

3-Increased diffusing capacity of the lungs.

4- Increased vascularity of the tissues.

5-Increased ability of the cells to utilize oxygen despite the low PO2 through increased number of mitochondria and oxidative enzymes activity.

**TABLE 5.4** Summary of Adaptive Respiratory Responses to High Altitude

| Parameter | Response to High Altitude |
|---|---|
| Alveolar $P_{O_2}$ | ↓ (due to decreased barometric pressure) |
| Arterial $P_{O_2}$ | ↓ (hypoxemia) |
| Ventilation rate | ↑ (hyperventilation due to hypoxemia) |
| Arterial pH | ↑ (respiratory alkalosis due to hyperventilation) |
| Hemoglobin concentration | ↑ (increased red blood cell concentration) |
| 2,3-DPG concentration | ↑ |
| $O_2$-hemoglobin dissociation curve | Shifts to right; increased $P_{50}$; decreased affinity |
| Pulmonary vascular resistance | ↑ (due to hypoxic vasoconstriction) |
| Pulmonary arterial pressure | ↑ (secondary to increased pulmonary resistance) |

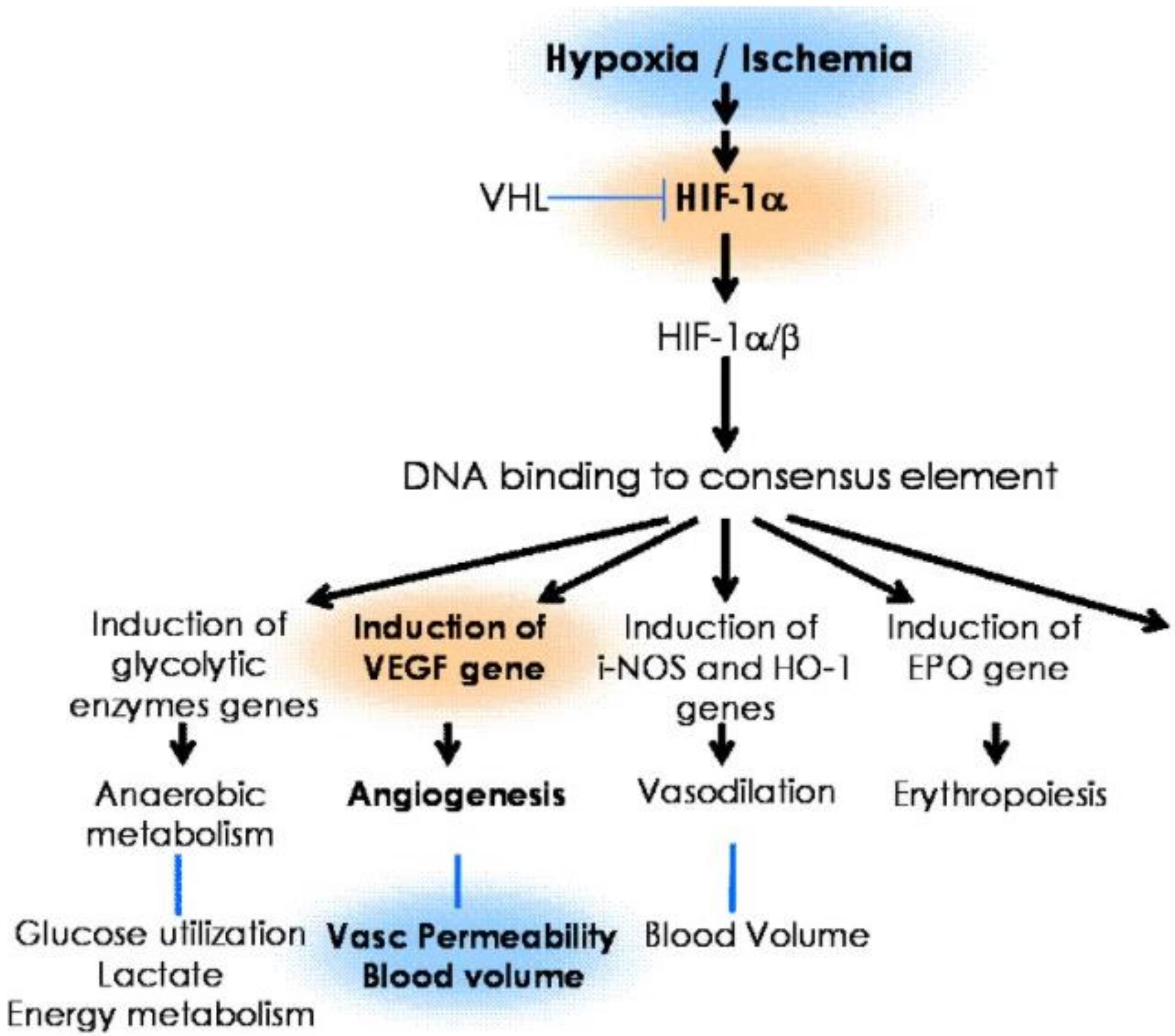
*2,3-DPG*, 2,3-diphosphoglycerate.

# HYPOXIA-INDUCIBLE FACTORS ( HIFs): A MASTER SWITCH" FOR THE BODY'S RESPONSE TO HYPOXIA

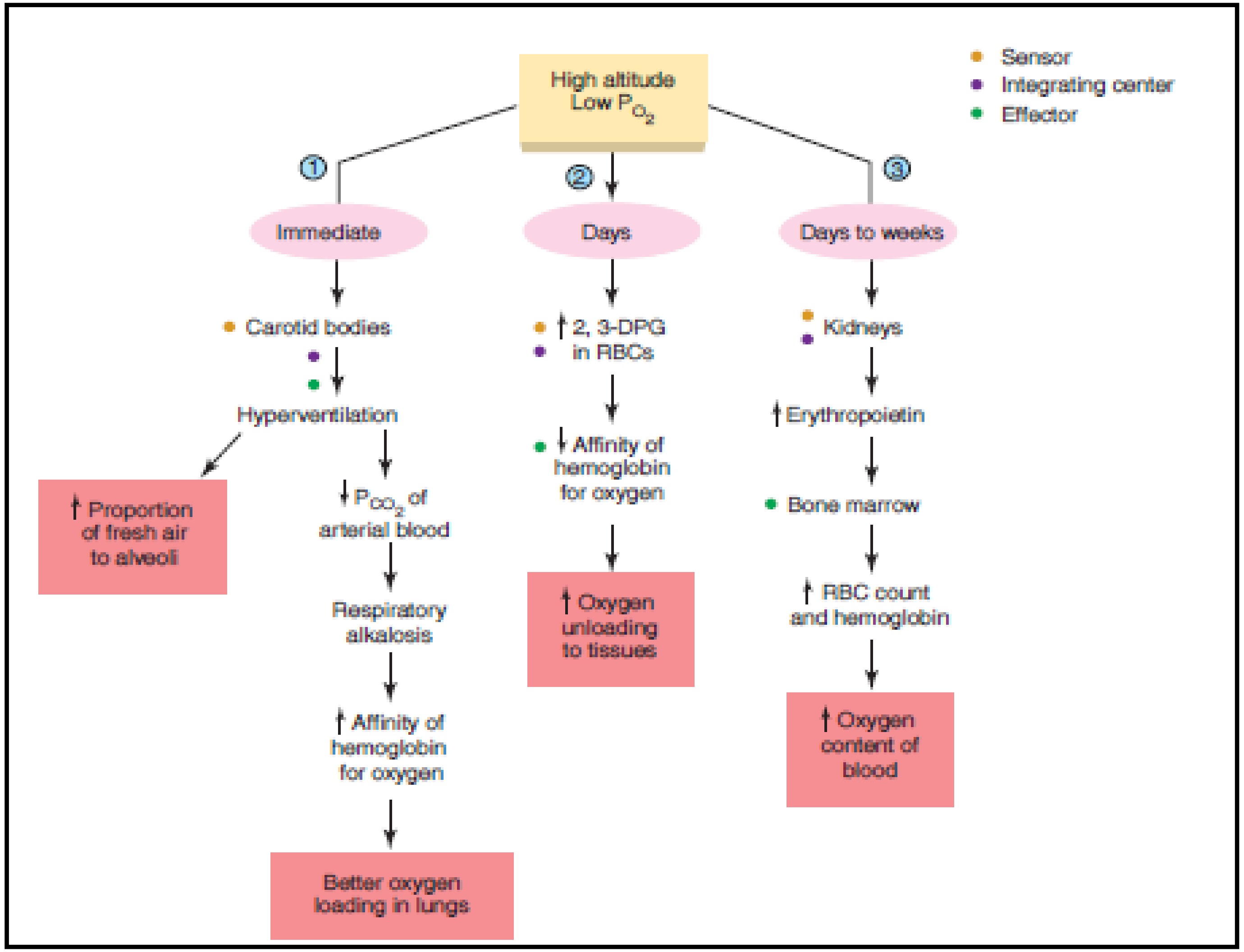
- *Hypoxia-inducible factors* (HIFs) are DNA-binding transcription factors that respond to decreased oxygen availability and activate several genes that encode proteins needed for adequate oxygen delivery to tissues and energy metabolism.
- HIFs are found in virtually all oxygen-breathing species, ranging from primitive worms to humans.
- **Some of the genes controlled by HIFs, especially HIF-1, include the following:**
    - ➢ Genes associated with vascular endothelial growth factor, which stimulates angiogenesis.
    - ➢ Erythropoietin genes that stimulate red blood cell production.
    - ➢ Mitochondrial genes involved with energy utilization.
    - ➢ Glycolytic enzyme genes involved with anaerobic metabolism.
    - ➢ Genes that increase availability of nitric oxide, which causes pulmonary vasodilation.

# Cont… HIFs

- In the presence of adequate oxygen, the subunits of HIF required to activate various genes are downregulated and inactivated by specific HIF hydroxylases.
- In hypoxia, the HIF hydroxylases are themselves inactive, allowing the formation of a transcriptionally active HIF complex. Thus, the HIFs serve as a “master switch” that permits the body to respond appropriately to hypoxia.



# Body response to high altitude



# Chronic Breathing of Low $O_2$ Stimulates Respiration — Phenomenon of "Acclimatization"

- The reason for acclimatization is that, within 2 to 3 days, the respiratory center in the brain stem loses about four fifths of its sensitivity to changes in $PCO_2$ and hydrogen ions.
- The excess blow-off of $CO_2$ that normally would inhibit an increase in respiration fails to occur and low $O_2$ can drive the respiratory system.
- Mountain climbers who ascend a mountain slowly, over a period of days rather than hours, can breath much more deeply and therefore can withstand far lower atmospheric $O_2$ concentrations than when they ascend rapidly. **This phenomenon is called acclimatization.**
- Instead of the 70 percent increase in ventilation that might occur after acute exposure to low $O_2$, the alveolar ventilation often increases 400 to 500 percent after 2 to 3 days of low $O_2$, which helps immensely in supplying additional $O_2$ to the mountain climber.

# NATURAL ACCLIMATIZATION OF NATIVE PEOPLE LIVING AT HIGH ALTITUDES

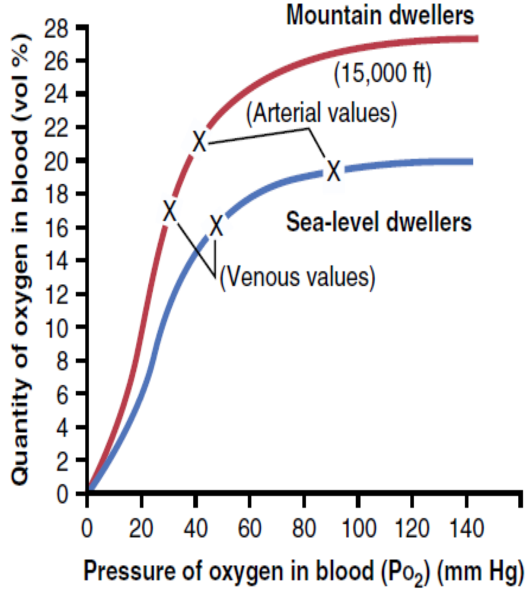



**Figure 44-2.** Oxygen-hemoglobin dissociation curves for blood of high-altitude residents *(red curve)* and sea level residents *(blue curve)* showing the respective arterial and venous $Po_2$ levels and oxygen contents as recorded in their native surroundings. *(Data from Pan American Health Organization. Oxygen-dissociation curves for bloods of high-altitude and sea-level residents. Life at high altitudes. Washington, DC: Pan American Health Organization Scientific Publication No. 140, 1966.)*

**Table 44-2 Differences in Work Capacities**

| | Work Capacity (% of Normal) |
|---|---|
| Unacclimatized | 50 |
| Acclimatized for 2 months | 68 |
| Native living at 13,200 feet but working at 17,000 feet | 87 |

# Acute mounting sickness- high altitude pulmonary edema

- Lower levels of oxygen and reduced air pressure are the primary causes of Acute Mountain Sickness.
- the onset of symptoms of Acute Mountain Sickness is usually within hours of arriving at that altitude.
- These symptoms may range from mild to severe depending on the severity of the condition.
- **Some of the symptoms of mild Acute Mountain Sickness are:**
- Dizziness, Headaches, Muscle pain, Inability to sleep, Nausea along with vomiting Irritable mood, Appetite loss, Swelling of the upper and lower extremities, Increased heartbeat, Difficulty breathing with any strenuous activity.

# Acute mounting sickness- high altitude pulmonary edema

- There may be fluid build-up in the lungs causing shortness of breath even with slight activity.
- The symptoms of severe form of Acute Mountain Sickness include:

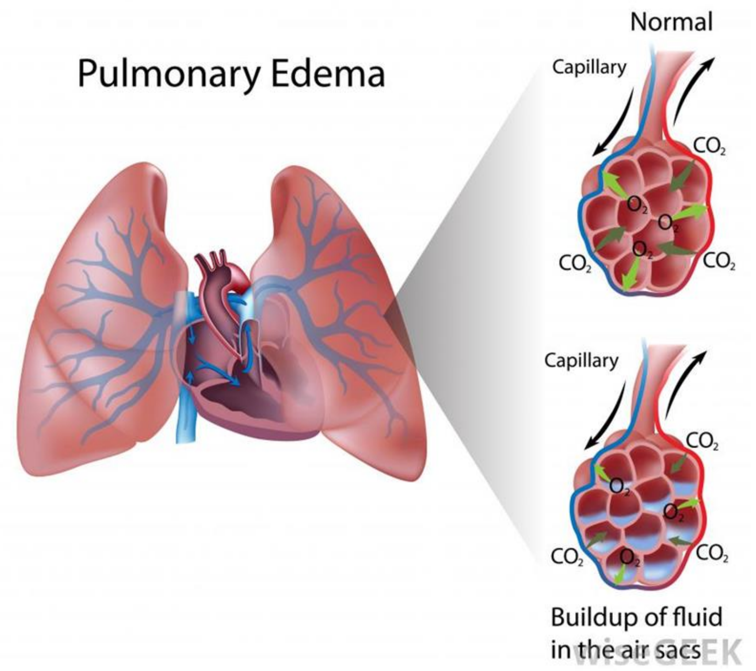
➢ Persistent coughing

➢ Chest congestion

➢ Individual looks pale

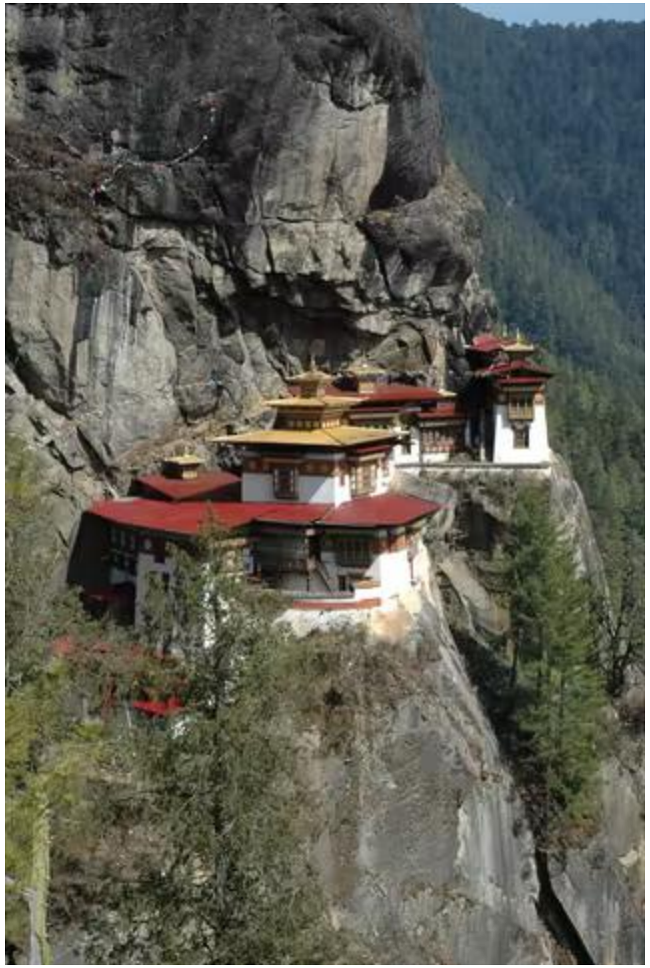
➢ Loss of balance

➢ Ambulation difficulties



# Chronic mountain sickness

- CMS is defined as a clinical syndrome that occurs in natives or lifelong altitude residents (>2500 m), and it is characterized by excessive erythrocytosis and severe hypoxemia.
- Frequently, it is associated with moderate or severe pulmonary hypertension that may evolve to cor-pulmonale and lead to congestive heart failure.
- The clinical picture of CMS gradually disappears upon descent to low altitudes and reappears after returning to high altitude.



# Chronic mountain sickness

Typical CMS patient. Note the deep *purplish color* of lips and gums as a consequence of EE and low $SpO_2$. Vein dilatation is particularly evident in the lower limbs, and characteristic clubbing of fingers and marked cyanosis are evident in nail beds and palms of the hands.

- CMS, chronic mountain sickness; EE, excessive erythrocytosis.

Villafuerte FC, Corante N. Chronic Mountain Sickness: Clinical Aspects, Etiology, Management, and Treatment. *High Alt Med Biol*. 2016;17(2):61-69. doi:10.1089/ham.2016.0031

# Thank you

Reference: Guyton and Hall textbook of Medical Physiology

Stay safe & stay hydrated