Physical agents – Extreme environments

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Course plan

- Hypobaric and hyperbaric environments
  - Mechanisms
  - Health effects
  - Prevention

- Other hypoxic environments

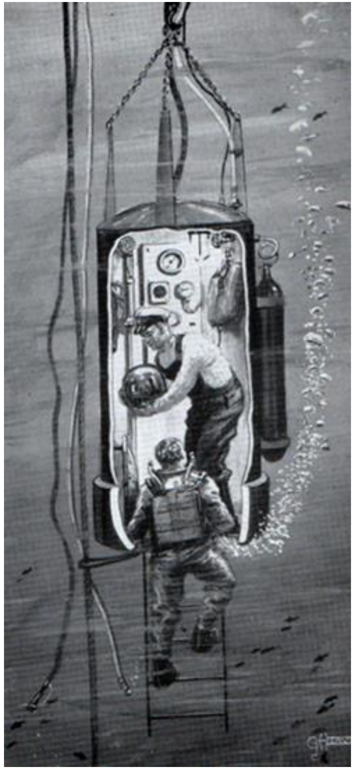
Hypo- and Hyperbaric environments

Normal pressure

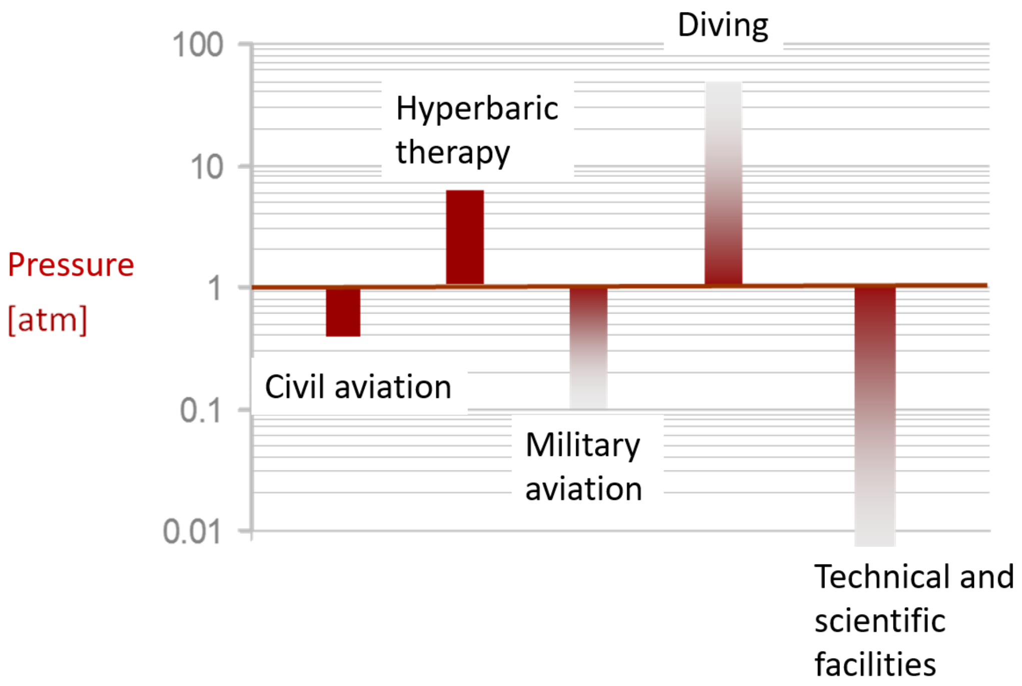
- The “weight” of the air column
- At sea level 1 atm ~100’000 Pa (N/m^2)
- This (enormous) pressure is not felt because our body is in balance with its environment

Pressure variation

- Depends on the density of the environment
- Underwater
  - ~ 1 additional atm per 10 m depth
- At altitude
  - ~ 50% of ambient pressure at 5500 m



Hypo- and Hyperbaric environments



Activities @t risk:

- Diving, diving medicine, tunnel boring machines
- Military and civil aviation, industrial and scientific facilities, Mountain climbing, space traveling

Hypo- and Hyperbaric environments

Possible health effects

- Many symptoms, **4 main categories**, grouped by mechanism
- Mostly short-term effects

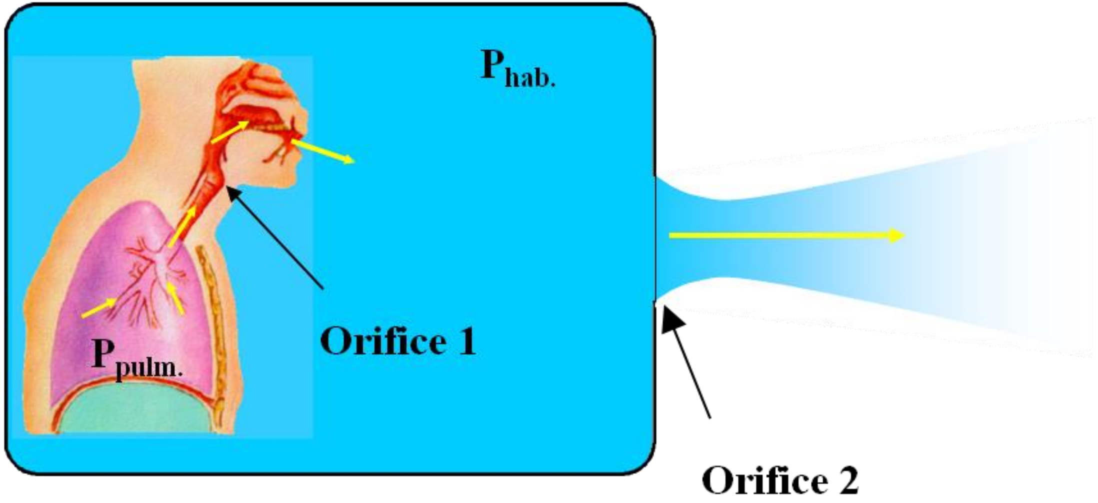
	Hypobaric	Hyperbaric
Barotraumas	Intestines, lungs, sinuses...	ear, intestines*, lungs*, sinuses*...
Decompression sickness	yes	yes
Hypoxia	yes	-
hyperoxia	-	yes
ebulism	yes	-

* When getting back to normal pressure

Barotrauma

Pulmonary overpressure

- When ambient pressure drops:
  - Increased gas volume in enclosed spaces (gas law)
  - Mechanical stress on physiological cavities (lung, ear, intestine…)

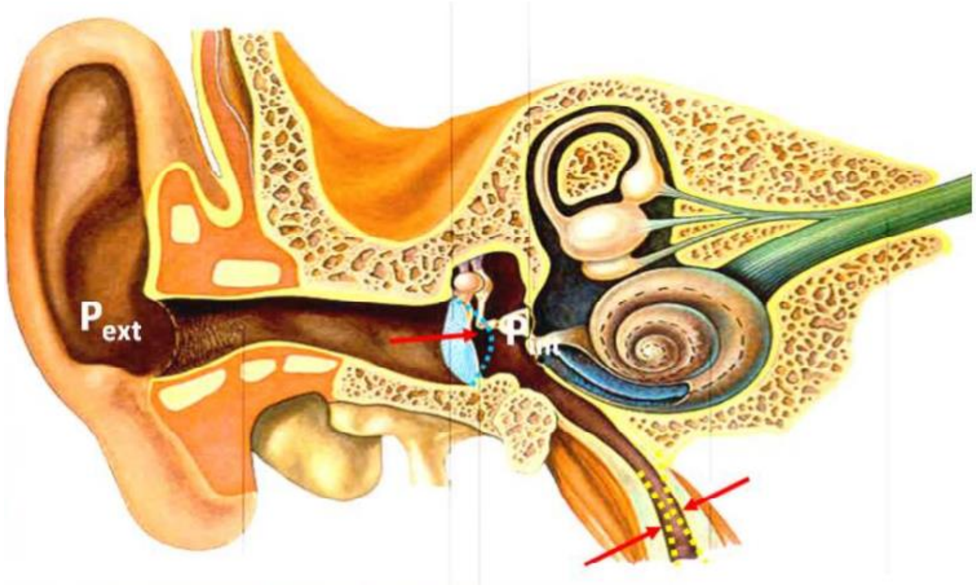


- Lung barotrauma (rupture):
  - Needs a minimal pressure ratio <2.3
  - Needs a fast change, leakage coefficient < 1/200 m^{-1}

Barotrauma

Ears overpressure

- Imbalance between the middle and external ear
- The eustachian tube act as a valve (normally)
  - Pext > Pint
  - Active balancing required
  - Balancing impossible from dP 120 hPa
- Consequence
  - Acute otitis
  - Tympanic rupture at around dP 530 hPa



Barotrauma, prevention

Influencing factors

- Pressure ratio ($P_{initial}$ / P_{final})
- Immediate manifestations

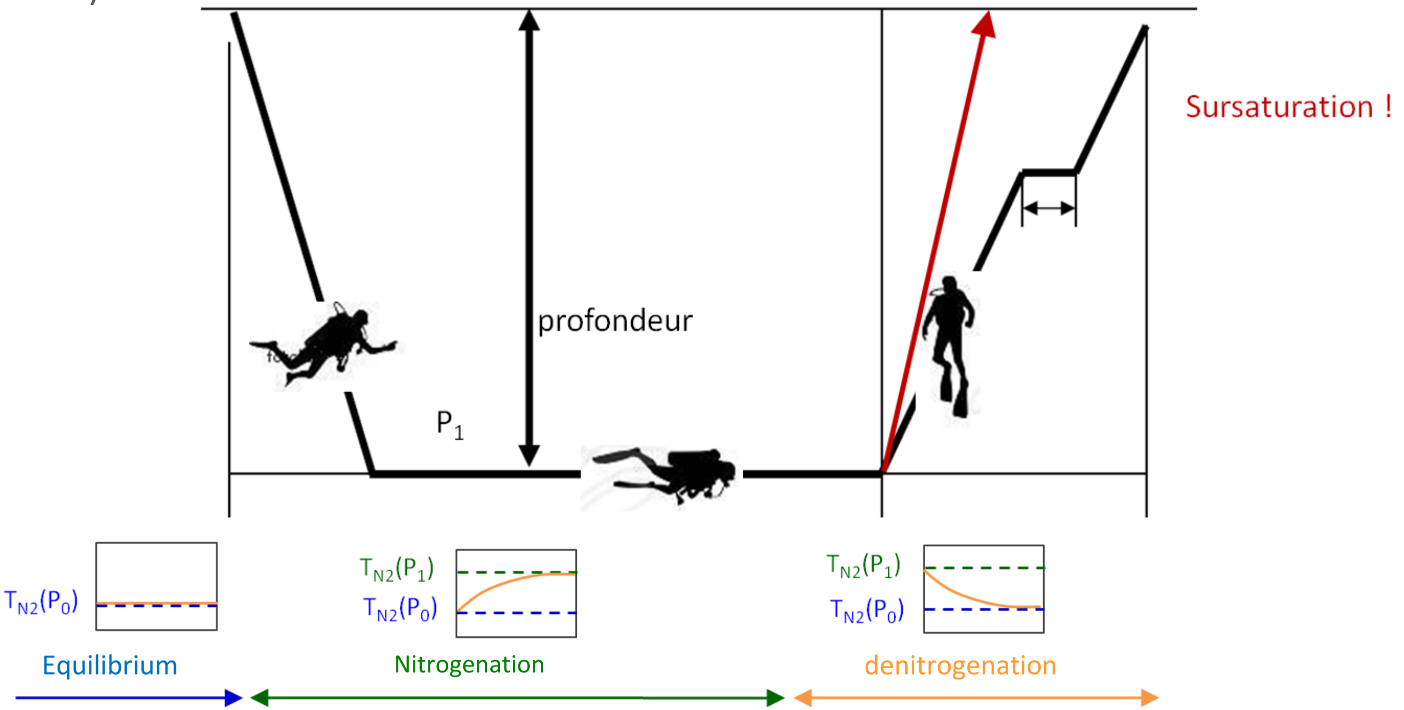
Prevention, management

• Pressure equalization	→	Valsalva maneuver the final
• pressure achieved	→	max depth in diving
• Limiting the rate of decompression	→	airplane's structure
• Return to “normal” pressure		

Decompression sickness

Tissue nitrogenation and denitrogenation

- Noise is measured in Decibels [dB] (logarithmic scale)



Case study

Nitrogenation of tissues

The partial pressure of nitrogen in the tissues increases progressively during the dive (according to an exponential relationship). Assuming a constant depth dive, the evolution of the partial pressure of nitrogen in a tissue can be written as:

$$P_{tissus}(t) = P_0 + [P_1 - P_0]e^{-kt}$$

Question (4.4a)

How long do you have to stay in the water for your body to be in equilibrium with the N_2 ambient pressure ? We consider here that equilibrium is reached if 90% of the initial pressure gradient is compensated

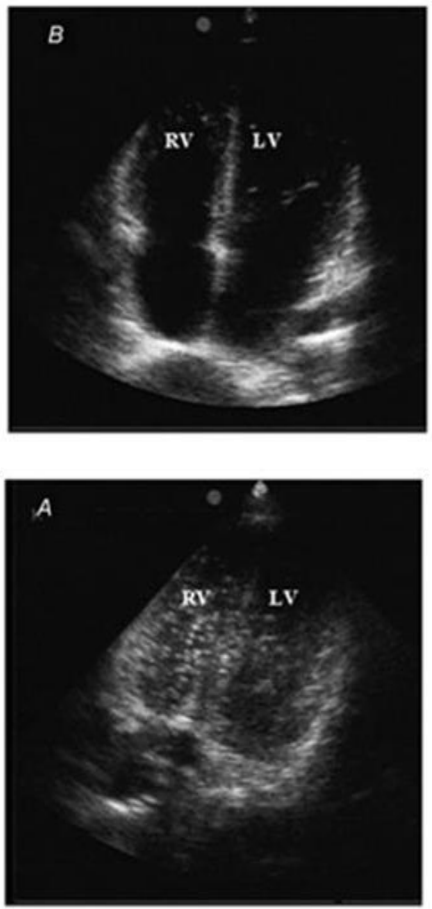
Decompression sickness

Tissue denitrogenation

- Excessive nitrogen stored in the body becomes supersaturated when pressure decrease
- Needs pressure ratio > 2
- Appearance of microbubbles, that circulates through the blood vessels

Infuencing factors

- Nitrogen tension in the tissue (concentration)
  - Ambient pressure, length of stay
- Decompression rate
- Morphology, physiology



Cardiac ultrasound: (a) supersaturated, (b) normal

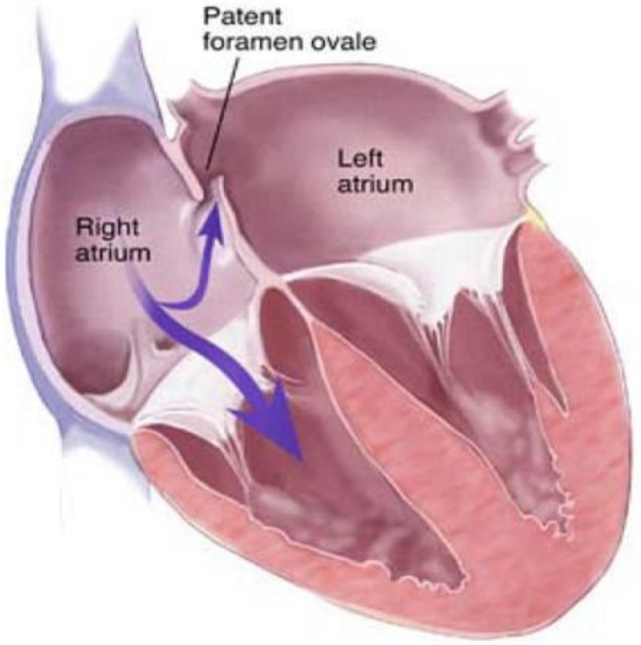
Decompression sickness

Consequences

- Progressive accumulation, capillaries…
- Joints, spinal cord, brain capillaries, inner ear
- Delayed effect (3 min to a few hour)
- Symptoms (tingling, joint pain)

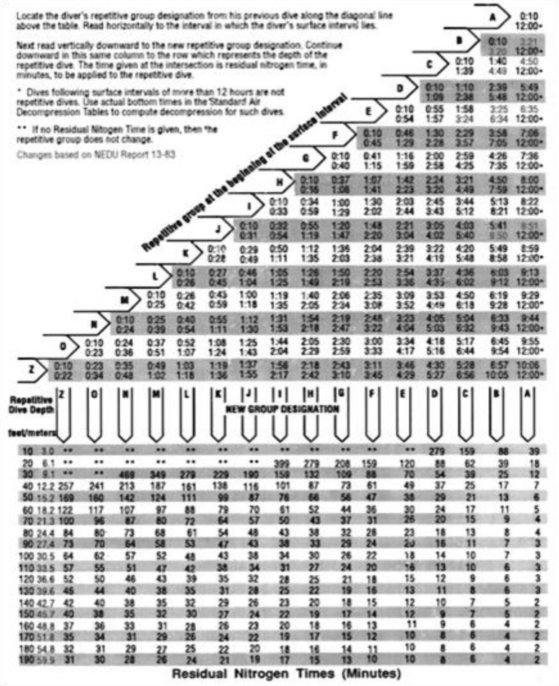
The foramen ovale

- Short circuit between the left and right atrium
- Open at a fetal stage, closed at birth
- In 10-35% of the population, the foramen is patent, kept shut by the internal heart pressure



Section of the heart with a patent foramen ovale

Decompression sickness



Prevention

- Diving saturation tables
- Depth and time limits
- Decompression time

Hyperbaric treatment center

Treatment

- Hyperbaric oxygen therapy

Hyperoxia

Oxygen in excess

- Hyperoxygenation
- Chronic pulmonary effect (Lorrain Smith)
  - Chronic alveolitis
  - pO_2 > 40 kPa
- Neurotoxic effect (Paul Bert)
  - Spasm, epileptic seizure
  - pO_2 > 200 kPa

Drunkenness

- N_2 in excess (air breathing)
- Dizziness, light-headedness, intoxication
- > 6 atm

Ebullism (hypobaric environment only)

Mechanism

- Extreme hypobaric environment (aerospace)
- If ambient pressure reach the vapor pressure of vater at 37°C (63 hPa)
- The blood boils

Influencing factors

- Absolute pressure attained
- Instantaneous

Prevention

- Stay on earth

Case study

Diving to the top

Mr. Grandbleu is diving in spring in a mountain lake located at an altitude of 2400 meters. His equipment is in good condition, and he dives respecting the profile indicated by his dive tables. A few minutes after getting out of the water, however, Mr. Granbleu began to feel tingling and joint pain. What happened?

Question (4.4 b)

What happened and why ?

Hypoxia

Hypoxic hypoxia

Confined spaces

- Exposure situations
- Prevention

Other hypoxic environments

Hypoxic Hypoxia

The oxygen cascade

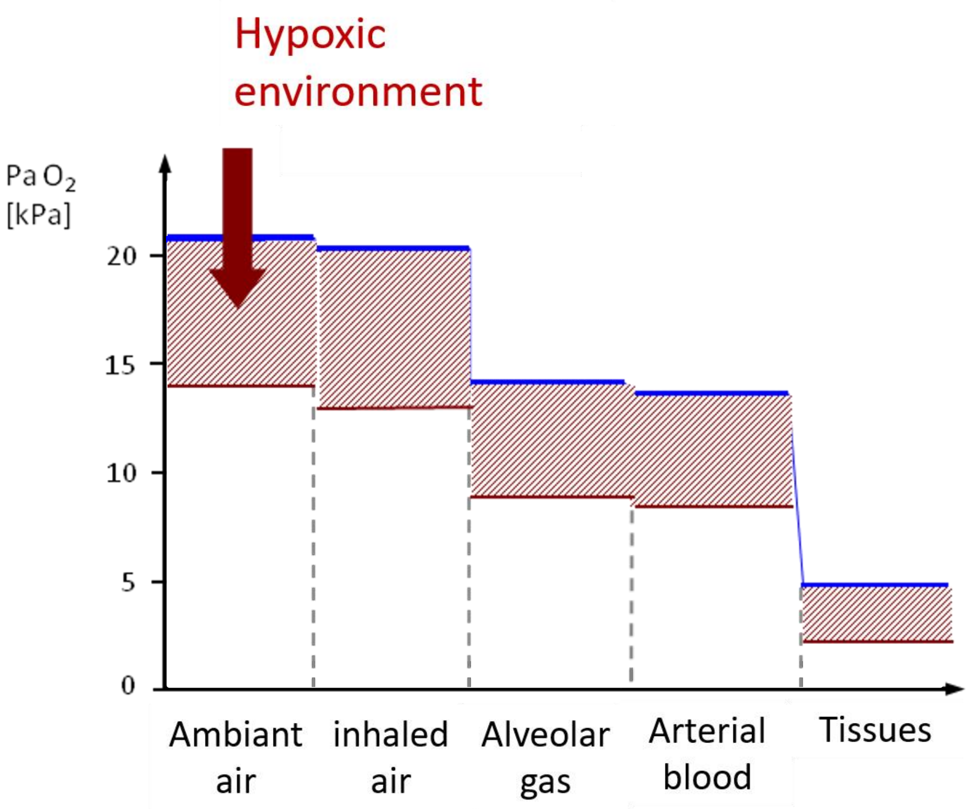
- Partial pressure in oxygen pO_2: 21.2 kPa (normobaric environment)
- The partial pressure in the tissues is much lower, around 5%

Hypoxia

- Oxygen deficiency

Hypoxic hypoxia

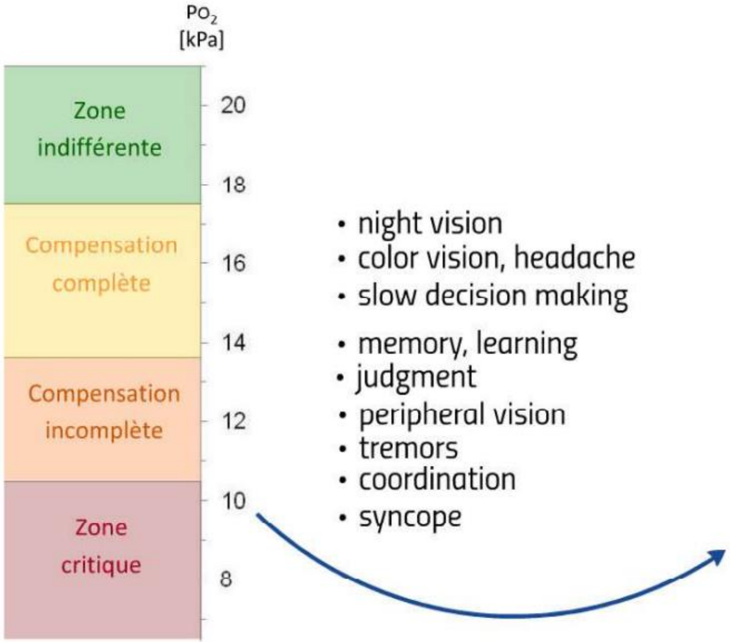
- oxygen deficiency due to insufficient oxygen in the air

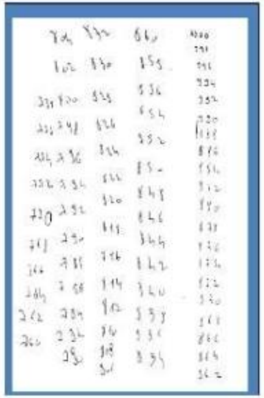


Hypoxic Hypoxia, effects

Acute exposure

- Immediate neurological effects





Writing test under hypoxia

Prolonged hypoxia

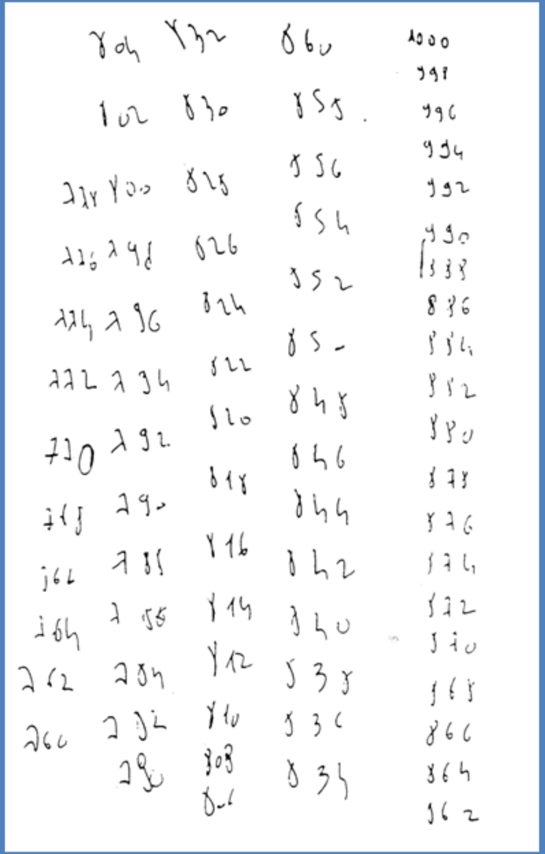
- Acute mountain sickness (AMS)
  - Benign 2500-3500 m (4-6h)
  - Pulmonary oedema (3-10 days)
  - Cerebral oedema

Hypoxic Hypoxia, effe

Acute exposure

- Immediate neurological effects

- night vision
- color vision, headache
- slow decision making
- memory, learning
- judgment
- peripheral vision
- tremors
- coordination
- syncope



Test d'écriture (10kP$_{O2}$)

Source: LAMAS

xia

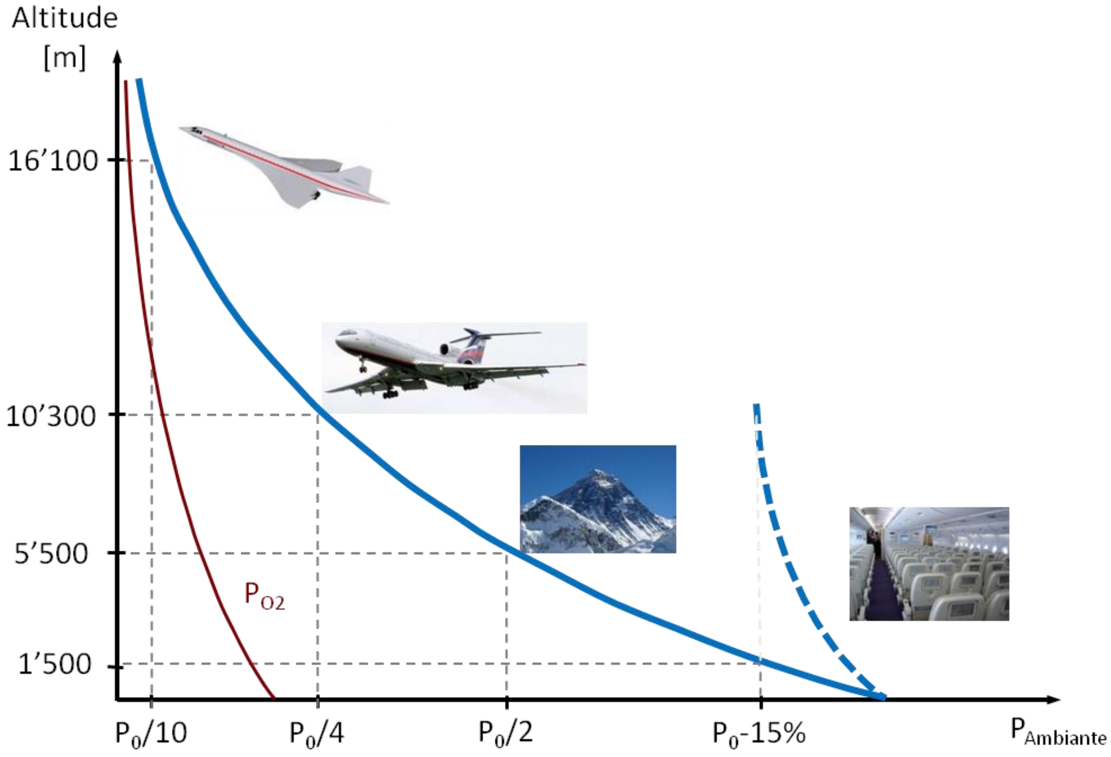
sickness (AMS)

3500 m (4-6h)

edema (3-10 days)

ema

Hypoxic hypoxia, altitude



Sectors involved

- Sports and leisure (high mountain)
- Civil and military aviation (about 3000 licenses in CH)

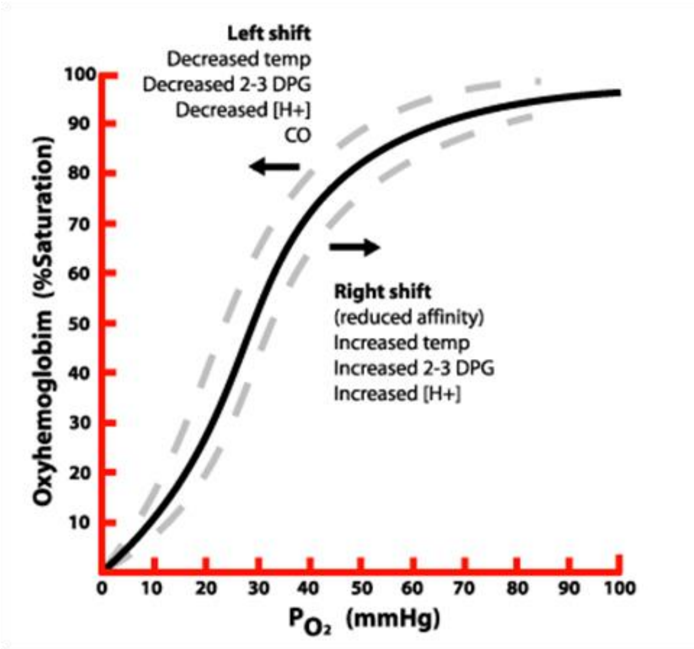
Sectors involved

- Dalton’s law
- PO_2 decreases proportionally to P_{amb}

Hypoxia

The oxygen saturation curve

- Relationship between O_2 partial pressure (ambient) and blood saturation



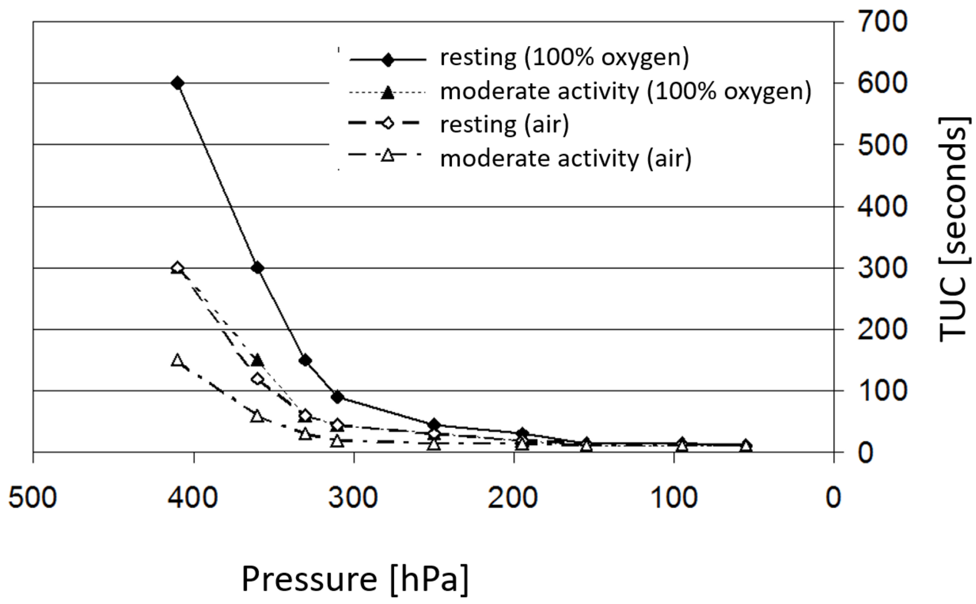
Influencing factors

- pO_2, Temperature, Blood pH,
- Environmental factors
  - Age, cardiovascular and respiratory diseases

Hypoxia, accidental decompression

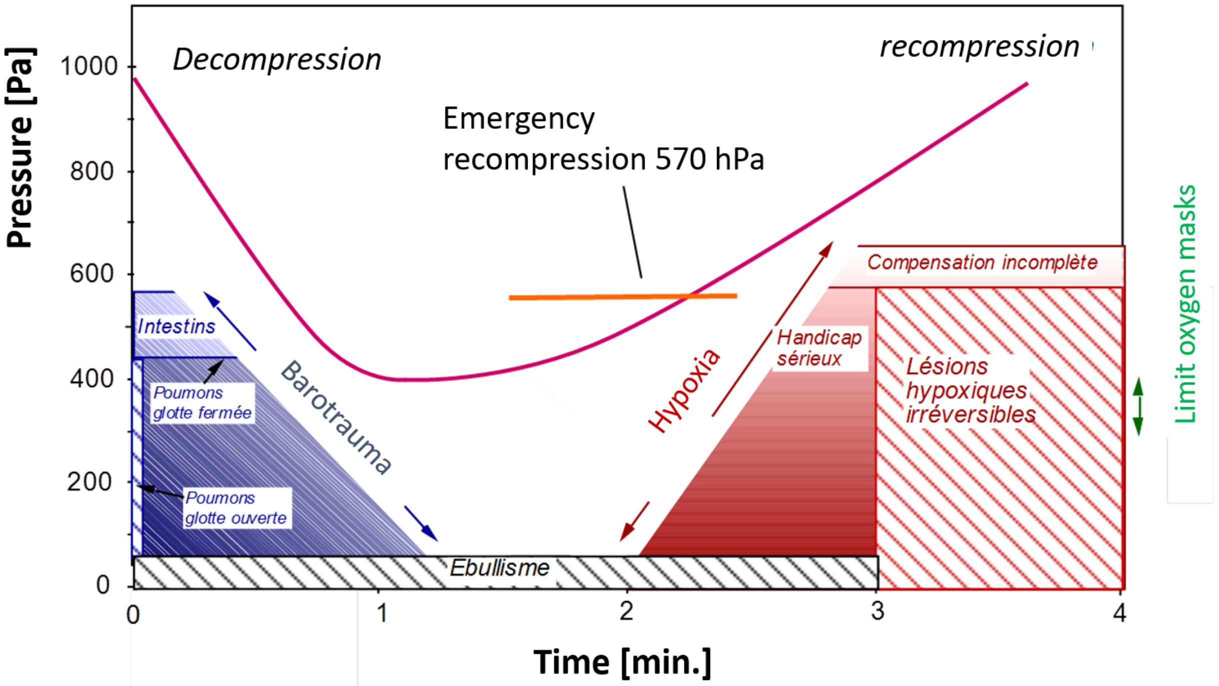
Time of useful consciousness

- Ability to initiate rescue actions
- In case of rapid decompression < 30s



Hypoxia, accidental decompression

Decompression and emergency recompression (aviation)



Confined spaces

Definition

- Totally or partially closed volume
- Not conceived for continuous use
- Accessible only through limited openings (restricted entrances/exits), but :
- Large enough for a person to enter and work in.

Hazards

- **Hypoxia**, intoxication, explosion

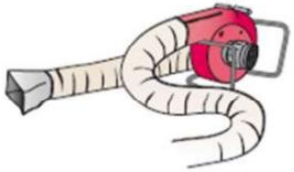
Prevention

- Wells, pits, sewers, tanks, vats (fermentation tanks), solos,…

Confined spaces

Preventive measures

- Ventilation of the space
  - Mechanical, natural drafts
- Removal of indoor pollution sources
  - E.g. combustion engines
- Air quality monitoring
  - Oxygen measurements, other pollutants
- Personal protection
  - Self-contained breathing apparatus (SCBA)
- Training, instruction
  - Intervention, rescue (over-accident)



Confined spaces

Requirements for pits and pipelines (in French)

- (1) if leakage of hazardous substances
- (2) if noxious atmosphere
- (3) not on man if artificial ventilation
- (4) if artificial ventilation insufficient

	Canalisations	Puits	Fosses	IES
Installations / Mesures	Canalisations d'eau potable, d'eau industrielle et d'eaux usées, installations d'évacuation de gaz de combustion et d'air vicié	Collecteurs d'eaux usées, bassins d'eaux pluviales (petits), puisards d'eaux d'infiltration, séparateurs, forages, puisards à pom-pes, puisards à pompes d'eaux souterraines	Bassins de décanta-tion, installations de décomposition, ouvrages destinés au traitement des boues de curage	Canalisations étroites destinées au transport de l'énergie et aux télécommunications
Ventiler artificiellement (A) naturellement (N) (chiffre 4.1/6.1)	N (ventilation artificielle si conditions particulières)	A	A	A 1) 2)
Mesure des gaz et des vapeurs (chiffre 4.2/6.2)	obligatoire (recommandée en cas de ventilation artificielle)	recommandée (obligatoire dans les pui-sards d'eaux d'infiltration)	obligatoire	obligatoire (recommandée en cas de ventilation artificielle)
Eviter les sources d'inflammation (chiffre 4.3/6.3)	Ex 2)	Ex 4)	Ex 2) 4)	Ex 1) 2)
Porter un appareil isolant (A)	A 2)	A 4)	A 2) 4)	A 2)
Appareil respiratoi-re isolant de se-cours sur l'homme (F) (chiffre 4.6/6.4)	F 3)			
Assurer la sur-veillance et mettre à disposition les moyens de sauvetage (chiffre 3.2/4.3/ 5.2/6.5)	obligatoire	obligatoire	obligatoire	obligatoire 2)

Source: Suva 44062

Cryogenic liquids

Mechanism

- Rapid evaporation of cryogenic liquid
- 1 liter of N_2 produces ~0.7 m^3 of nitrogen gas (odorless and invisible)
- Lowering of the oxygen content by dilution

Sectors involved

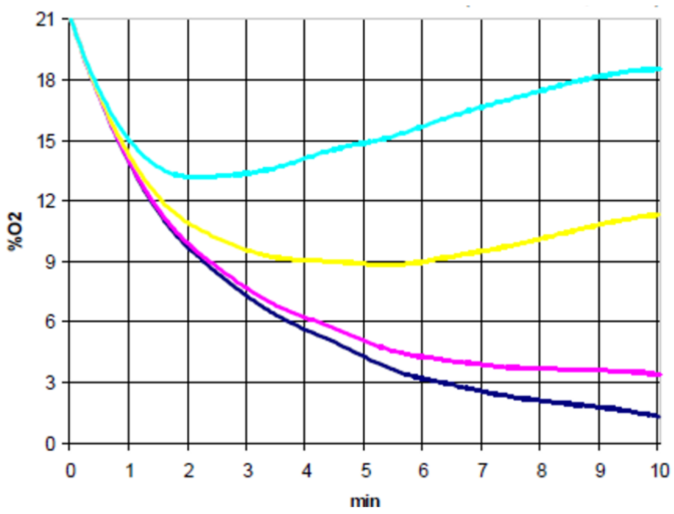
- Superconductivity physics laboratories
- Biology and medicine (sample conservation)
- Food
- Rapid freezing

Cryogenic liquid	Boiling point [°C]
Liquid Helium	-269
Liquid Nitrogen	-196
Liquid Argon	-186

Cryogenic liquid

Example

- Liquid nitrogen in laboratories for medically assisted reproduction
  - Initial cooling of the tank (e.g. after cleaning)
  - "Normal" evaporation and accidental situations

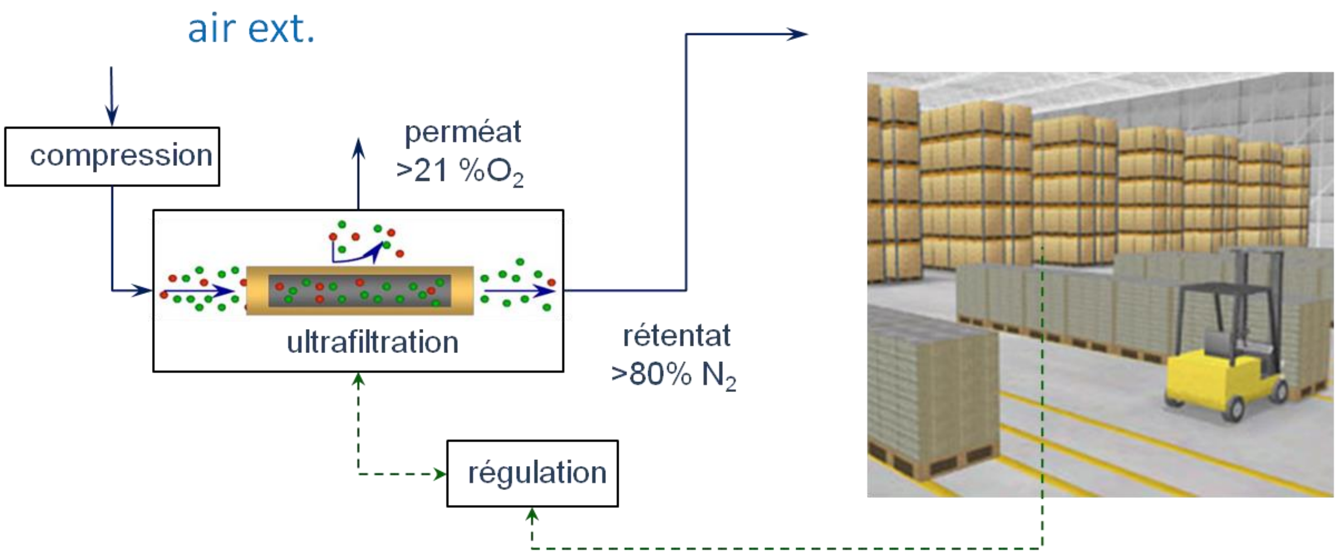


Oxygen level in a 30 m^3 room during chilling (Afsset 2008)

Intentional O_2 lowering

Sectors involved

- Inerting – chemical and petroleum industry
- Fire prevention – computer rooms, museums, libraries, storage
- Preservation – museums, libraries, food storage



Case study

Another nitrogen story

After filling a Dewar with liquid nitrogen at the nitrogen generator in the basement of the building, a lab technician takes the elevator back up to the lab. The elevator breaks down. the volume of the elevator is 3m^3, the air renewal negligible and that the Dewar loses 3ml of its content per minute (fictive case).

Question (4.4 c)

What will be the volume content in O_2 of the elevator after 1h ?