

Physical agents - extreme environments

Hypobaric and hyperbaric environments

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Hypo- and hyperbaric environments

Normal pressure

- The "weight" of the air column.
- At sea level 1atm \sim 100'000 Pa (N/m²).
- 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 10m depth
- At altitude
 - $\frac{1}{2}$ ambient pressure at 5500m

Hypo- and hyperbaric environments

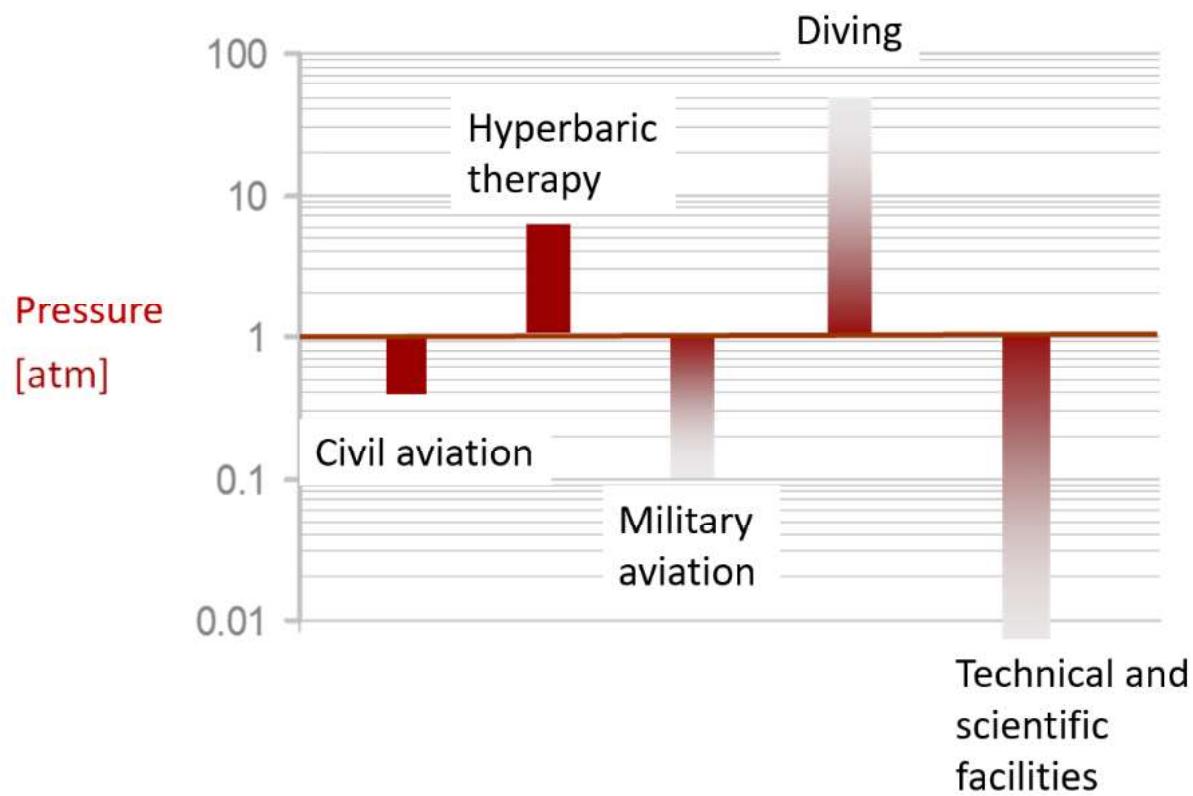
Environments...



- Occupations concerned
 - scuba divers, therapeutic hyperbaric chambers, tunnel boring machines
 - on-board personnel (aviation), industrial/scientific facilities

Hypo- and hyperbaric environments

Pressure variations



Hypo- and hyperbaric environments

4 main categories of effects

Similar mechanisms

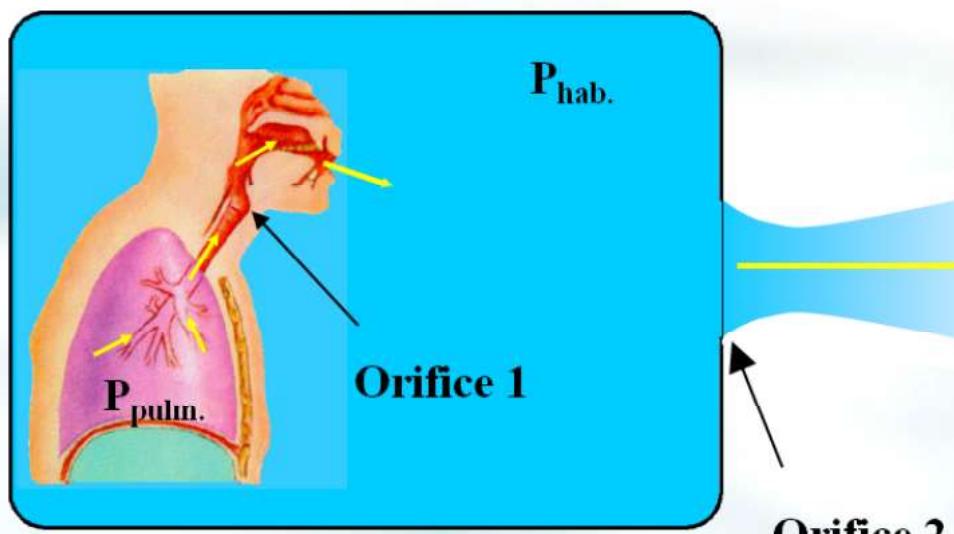
	Hypobaric	Hyperbaric
Barotraumas	Intestines, lungs, sinuses...	ear, intestines*, lungs*, sinuses* ...
Decompression sickness	yes	yes
Hypoxia	yes	-
hyperoxia	-	yes
ebulism	yes	-

*when getting back to normal pressure

Barotrauma, pulmonary overpressure

Drop in ambient pressure

- increased gas volumes in the cavities
- mechanical stress on physiological cavities



Barotrauma

- lung barotrauma
 - pressure ratio < 2.3 ,
 - leakage coefficient $< 1/200 \text{ m}^{-1}$

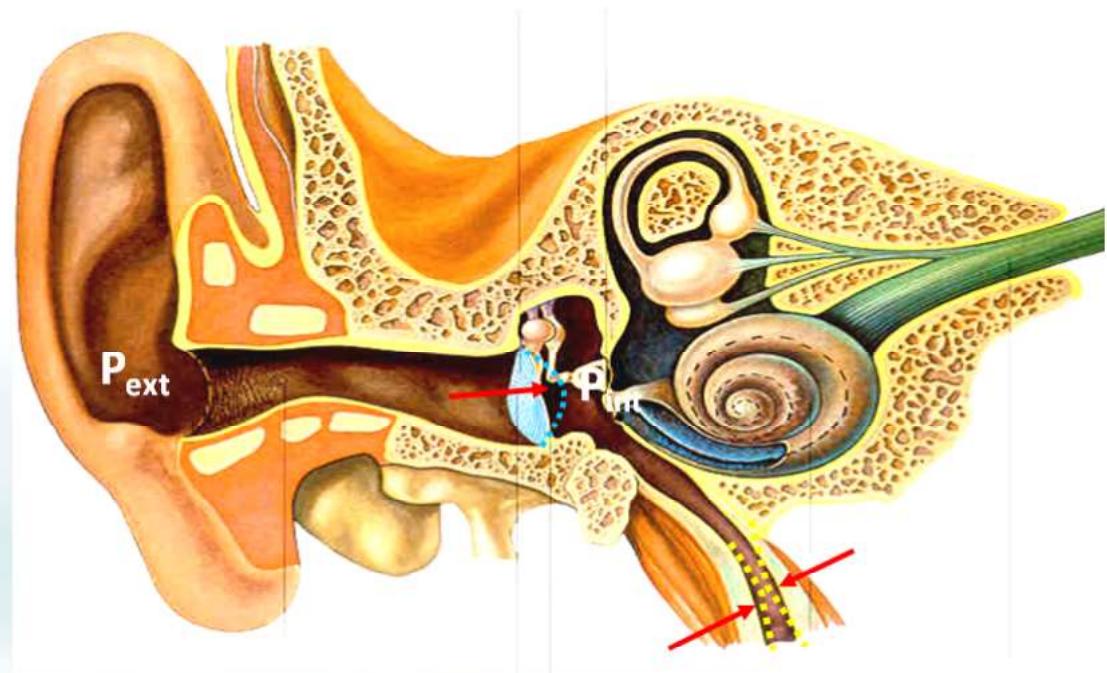
Barotrauma, ears overpressure

Imbalance when pressure is increased

- The eustachian tube acts as a valve
 - $P_{ext} > P_{int}$
 - active balancing required
 - balancing impossible from dP 120 hPa

Consequences

- acute otitis
- tympanic rupture at around dP 530 hPa



Barotrauma, prevention

Influencing factors

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

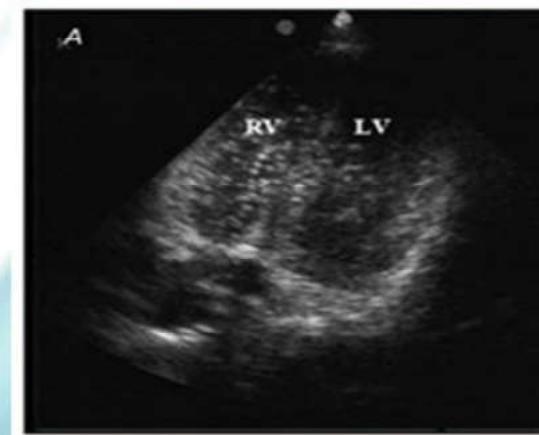
Prevention / management

- Pressure equalisation
- Limiting the final pressure achieved
- Limiting the rate of decompression
- Return to "normal" pressure

Decompression sickness

Tissues denitrogenation

- Decrease in solubility of dissolved nitrogen in the body with decreasing pressure
- Pressure drop greater than 2
- Supersaturation, appearance of microbubbles



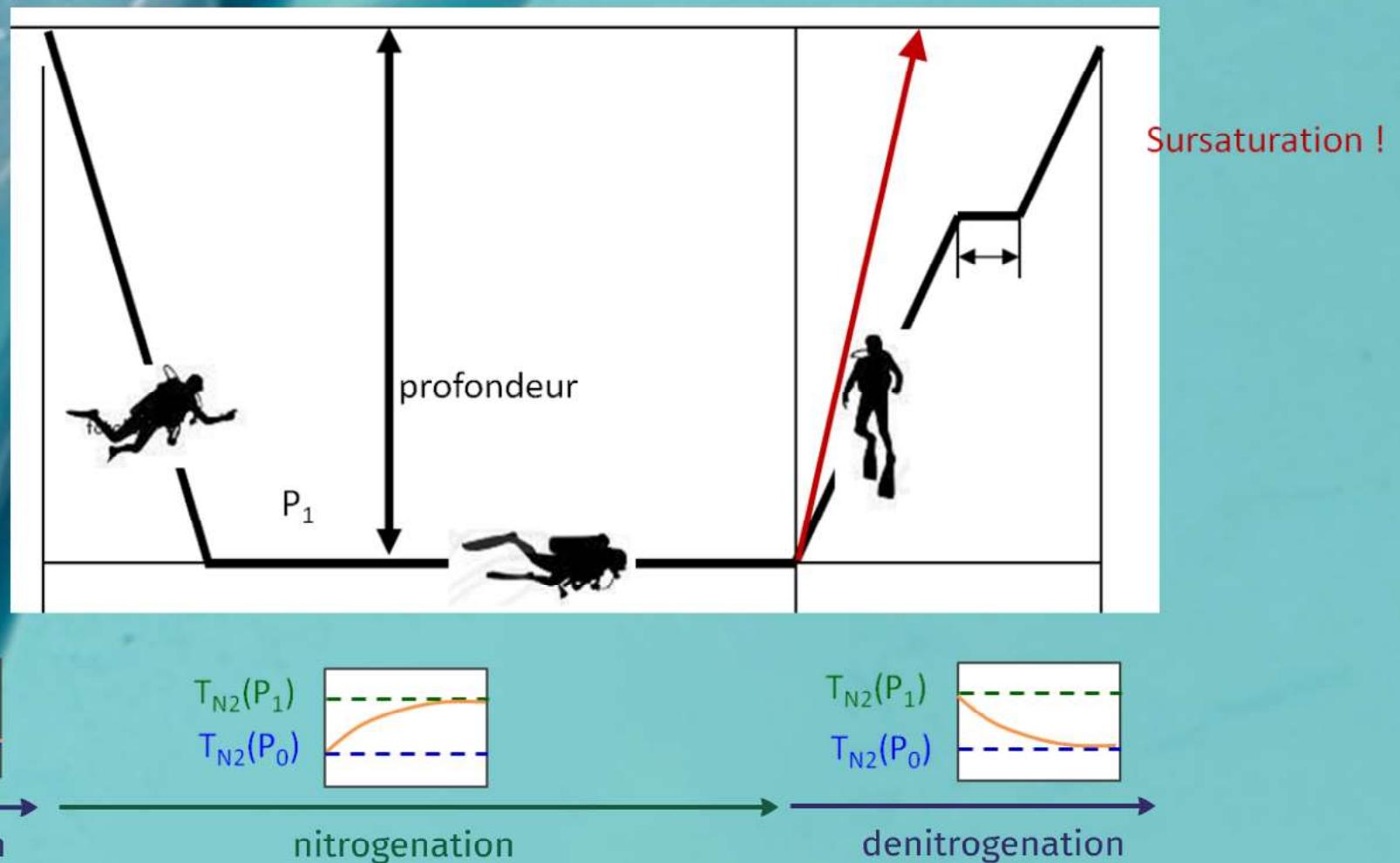
Influencing factors

- Nitrogen tension in the tissues
 - Pressure, length of stay
 - Decompression rate
- Decompression rate, pressure ratio
- Morphology, physiology

*cardiac ultrasound (a)
supersaturated (b) normal*

Decompression sickness

Diving and supersaturation



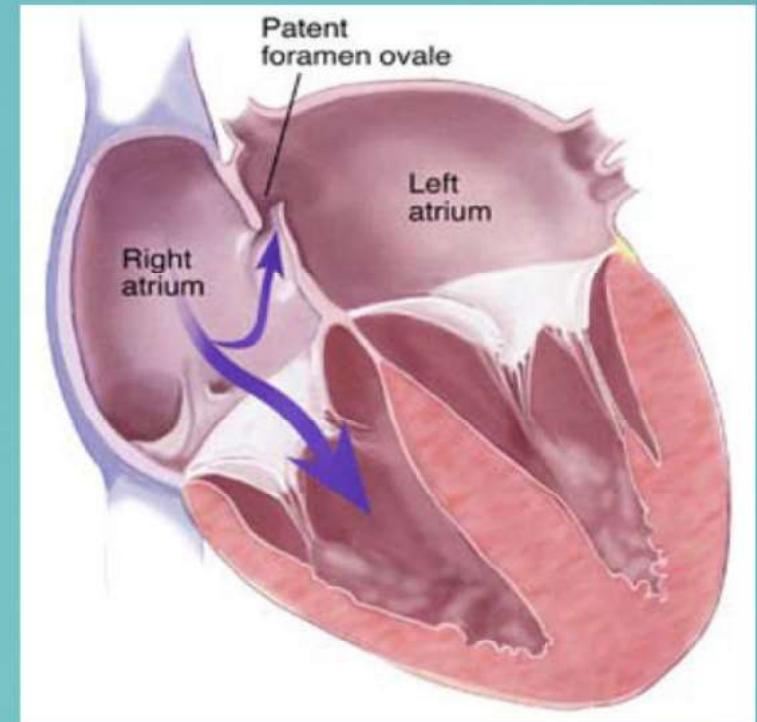
Decompression sickness

Consequences

- Progressive accumulation, blockage in capillaries...
- Joints, spinal cord, brain capillaries, inner ear
- Delayed effects (3 min to a few hours)
- Symptoms (tingling, joint pain)

The foramen ovale

- Short circuit between the right and left atrium
- Dissolved in the body with the lowering of the pressure



section of the heart with a patent foramen ovale

Decompression sickness Prevention

- Saturation curves
- Depths and time limits
- Decompression limits
- Movements in altitude



Hyperbaric Treatment Center

Locate the diver's repetitive group designation from his previous dive along the diagonal line above the table. Read horizontally to the interval in which the diver's surface interval lies.

Next read vertically downward to the new repetitive group designation. Continue downward in this same column to the row which represents the depth of the repetitive dive. The time given at the intersection is residual nitrogen time, in minutes, to be applied to the repetitive dive.

* Dives following surface intervals of more than 12 hours are not repetitive dives. Use actual bottom times in the Standard Air Decompression Tables to compute decompression for such dives.

** If no Residual Nitrogen Time is given, then the repetitive group does not change.

Changes based on NEDU Report 13-83

Repetitive group at the beginning of the surface interval

A	0:10	1:10	2:30	5:49	
B	0:10	1:20	2:00	5:49	
C	0:10	1:40	4:50		
D	0:10	1:10	2:30	5:49	
E	0:10	0:55	1:58	3:25	6:35
F	0:10	0:45	1:29	2:48	3:57
G	0:10	0:41	1:16	2:00	2:59
H	0:10	0:37	1:07	1:42	2:34
I	0:10	0:34	1:00	1:30	2:03
J	0:10	0:32	0:55	1:20	2:05
K	0:10	0:29	0:50	1:12	1:36
L	0:10	0:27	0:46	1:05	1:28
M	0:10	0:26	0:43	1:00	1:19
N	0:10	0:25	0:40	0:55	1:12
O	0:10	0:24	0:37	0:52	1:08
Z	0:10	0:23	0:35	0:49	1:03
	0:22	0:34	0:48	1:02	1:18
					1:36
					1:55
					2:17
					2:42
					3:10
					3:45
					4:29
					5:27
					6:56
					10:05
					12:00

Repetitive Dive Depth feet/meters	NEW GROUP DESIGNATION															
	Z	O	N	M	L	K	J	I	H	G	F	E	D	C	B	A
10 3.0 **	**	**	**	**	**	**	**	**	**	**	**	**	279	159	88	39
20 6.1 **	**	**	**	**	**	**	**	**	**	**	**	**	16	62	39	18
30 9.1 **	**	468	348	279	229	190	158	132	109	88	70	54	39	25	12	
40 12.2 257	241	213	187	161	138	116	101	87	73	61	49	37	25	17	7	
50 15.2 169	160	142	124	111	99	87	76	66	56	47	38	29	21	13	6	
60 18.2 122	117	107	97	88	79	70	61	52	44	36	30	24	17	11	5	
70 21.3 100	96	87	80	72	64	57	50	43	37	31	28	20	15	9	4	
80 24.4 84	80	73	68	61	54	48	43	38	32	28	23	18	13	8	4	
90 27.4 73	73	70	64	58	53	47	43	38	33	29	24	20	16	11	7	
100 30.5 64	62	57	52	48	43	38	34	30	26	22	18	14	10	7	3	
110 33.5 57	55	51	47	42	38	34	31	27	24	20	16	13	10	8	3	
120 36.6 52	50	46	43	39	35	32	28	25	21	18	15	12	9	6	3	
130 39.6 48	44	40	38	35	31	28	25	22	19	16	13	11	8	6	3	
140 42.7 43	40	38	35	32	29	26	23	20	18	15	12	10	7	5	2	
150 45.7 49	38	35	32	30	27	24	22	19	17	14	12	9	7	5	2	
160 48.8 37	36	33	31	28	26	23	20	18	16	13	11	9	6	4	2	
170 51.8 35	34	31	29	26	24	22	19	17	15	12	10	8	6	4	2	
180 54.8 32	31	29	27	25	22	20	18	16	14	11	10	8	6	4	2	
190 59.9 31	30	28	26	24	21	19	17	15	13	10	10	8	6	4	2	

Residual Nitrogen Times (Minutes)

Traitemet

- Hyperbaric oxygen therapy

Hyperoxia

Oxygen in excess

- hyperoxygenation
- chronic pulmonary effect (Lorrain-Smith)
 - chronic alveolitis
 - $PO_2 > 40kPa$
- neurotoxic effect (Paul Bert)
 - spasms, epileptic seizure
 - $PO_2 > 200kPa$

Drunkenness of the depths

N2 in excess (air breathing)

- dizziness, light-headedness, intoxication
- $> 6 \text{ atm}$

Hypoxia

Hypoxic hypoxia

Confined spaces

- Exposure situations
- Prevention

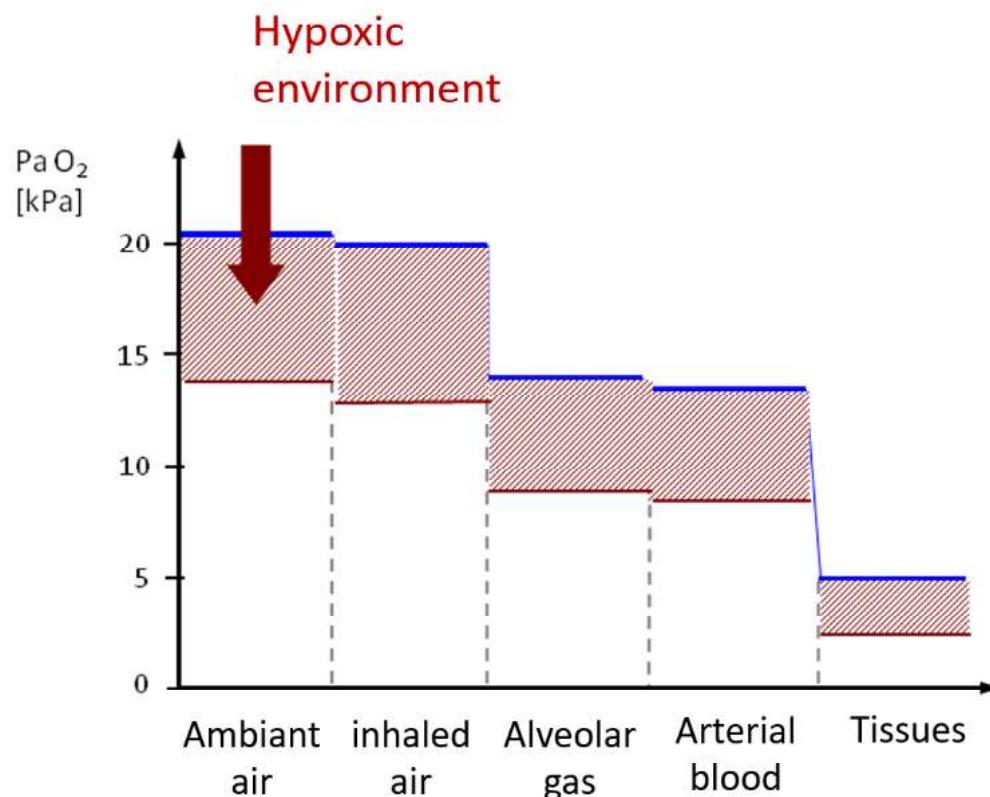


Other hypoxic environments

Hypoxic hypoxia

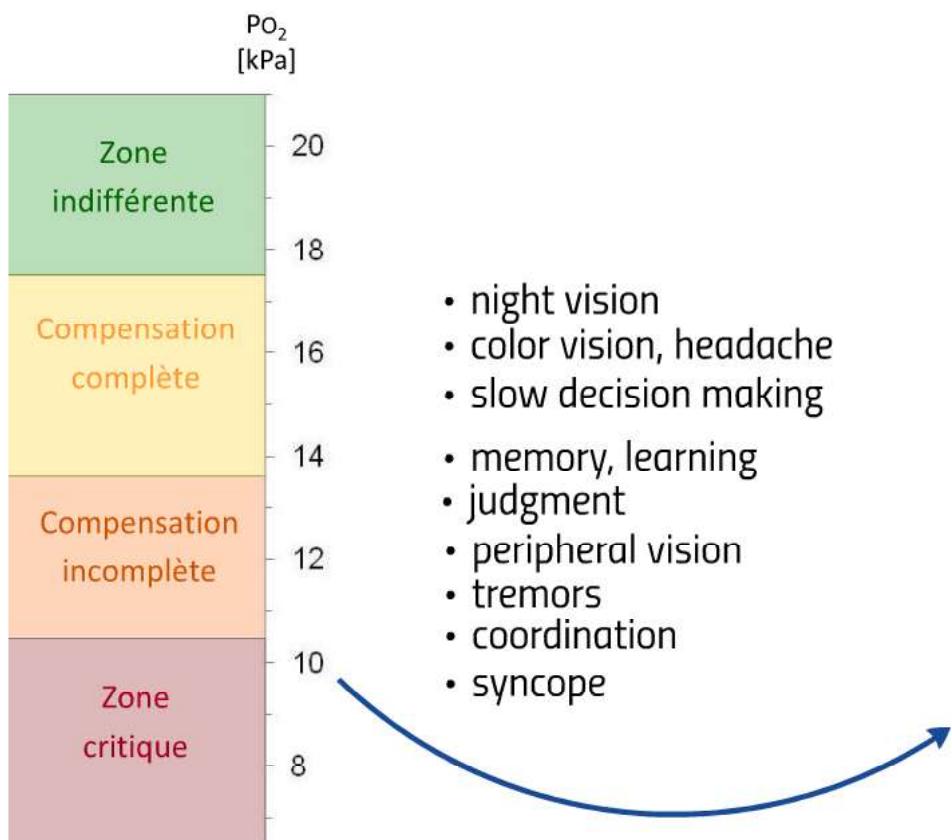
Ambient air

- 20.95% of Oxygen in air (78% N₂, Ar, CO₂,...)
- Partial pressure in Oxygen P_{O₂}: 21.2 kPa (159 mmHg) in a normobaric environment



- Hypoxia
 - Oxygen deficiency
- Hypoxic hypoxia
 - Decrease in the amount of oxygen in the inspired air

Effects of hypoxia



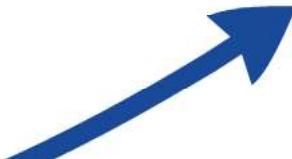
Prolonged hypoxia

- Acute mountain sickness (AMS)
 - benign 2500-3500 m (4-6 h)
 - pulmonary edema (3-10 days)
 - cerebral edema

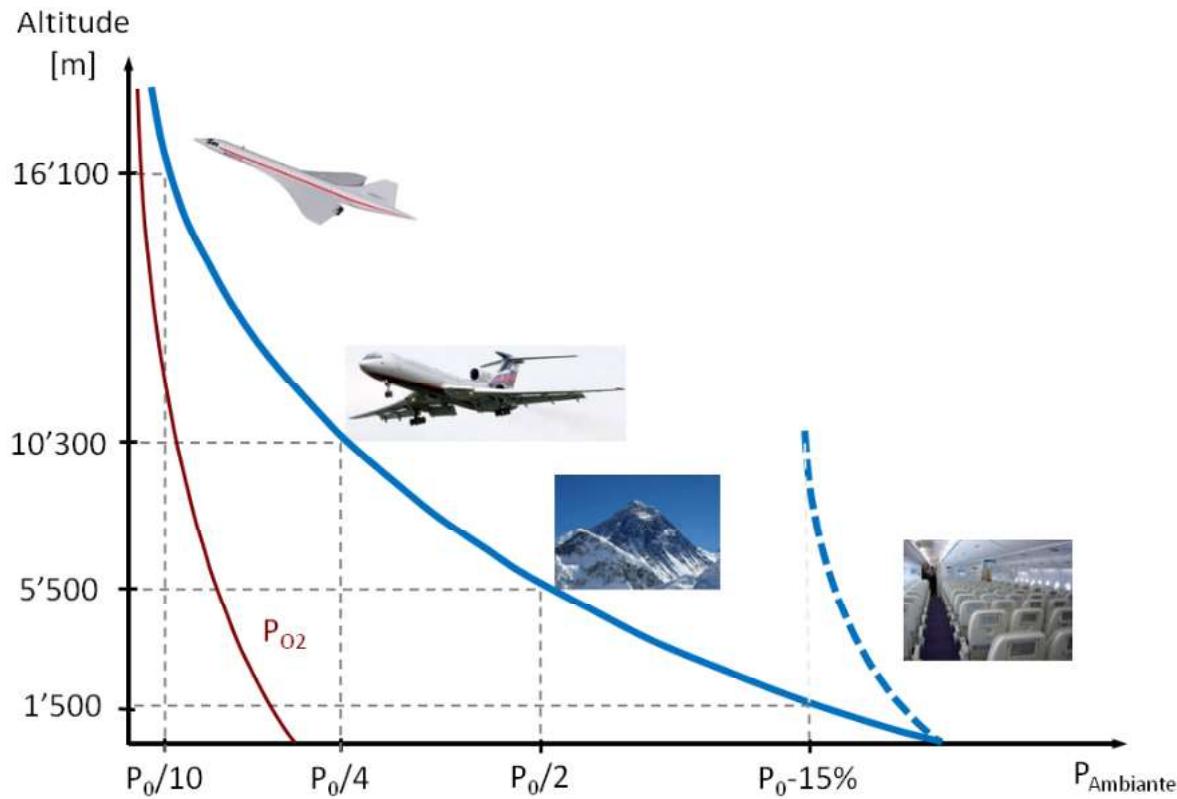
Y	2	3	4	5	6	7	8
U	1	2	3	4	5	6	7
I	0	1	2	3	4	5	6
O	9	8	7	6	5	4	3
A	5	4	3	2	1	0	9
E	8	7	6	5	4	3	2
T	3	2	1	0	9	8	7
S	6	5	4	3	2	1	0

writing test

704	732	660	1000
			798
102	830	755	990
			934
228	700	825	792
			1338
226	248	626	990
			836
224	296	824	836
			336
222	234	822	812
			880
710	292	820	878
			378
711	290	818	876
			376
762	288	816	874
			374
764	286	814	872
			372
762	284	812	870
			370
760	282	810	868
			368
78	308	838	864
			364
	8-1	836	162



The altitude



Sectors involved

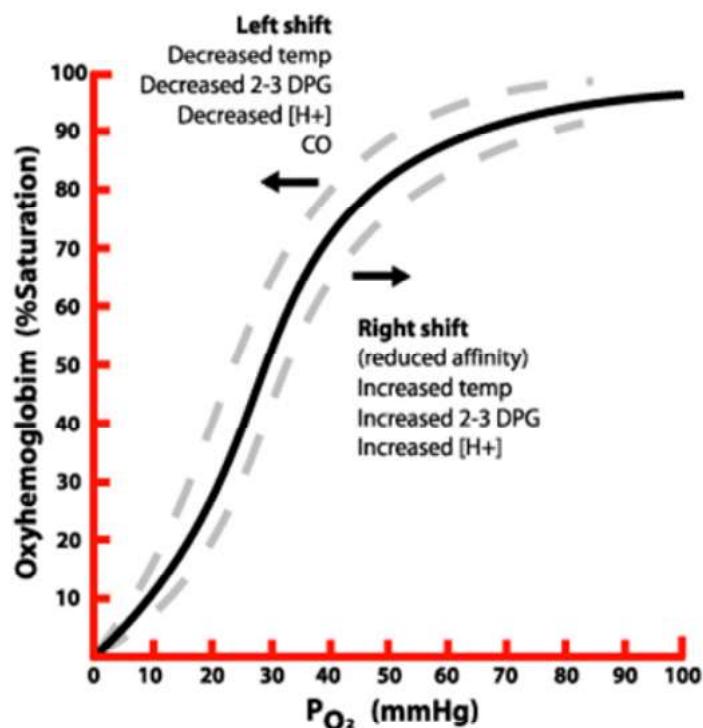
- Sports and leisure
 - high mountain
- Civil and military aviation
 - 3035 professional licenses

Effect of altitude

- Dalton's law
 - addition of the partial pressures
 - P_{O2} is proportional to $P_{\text{Amb.}}$

The oxygen saturation curve

Relationship between O₂ partial pressure and blood saturation



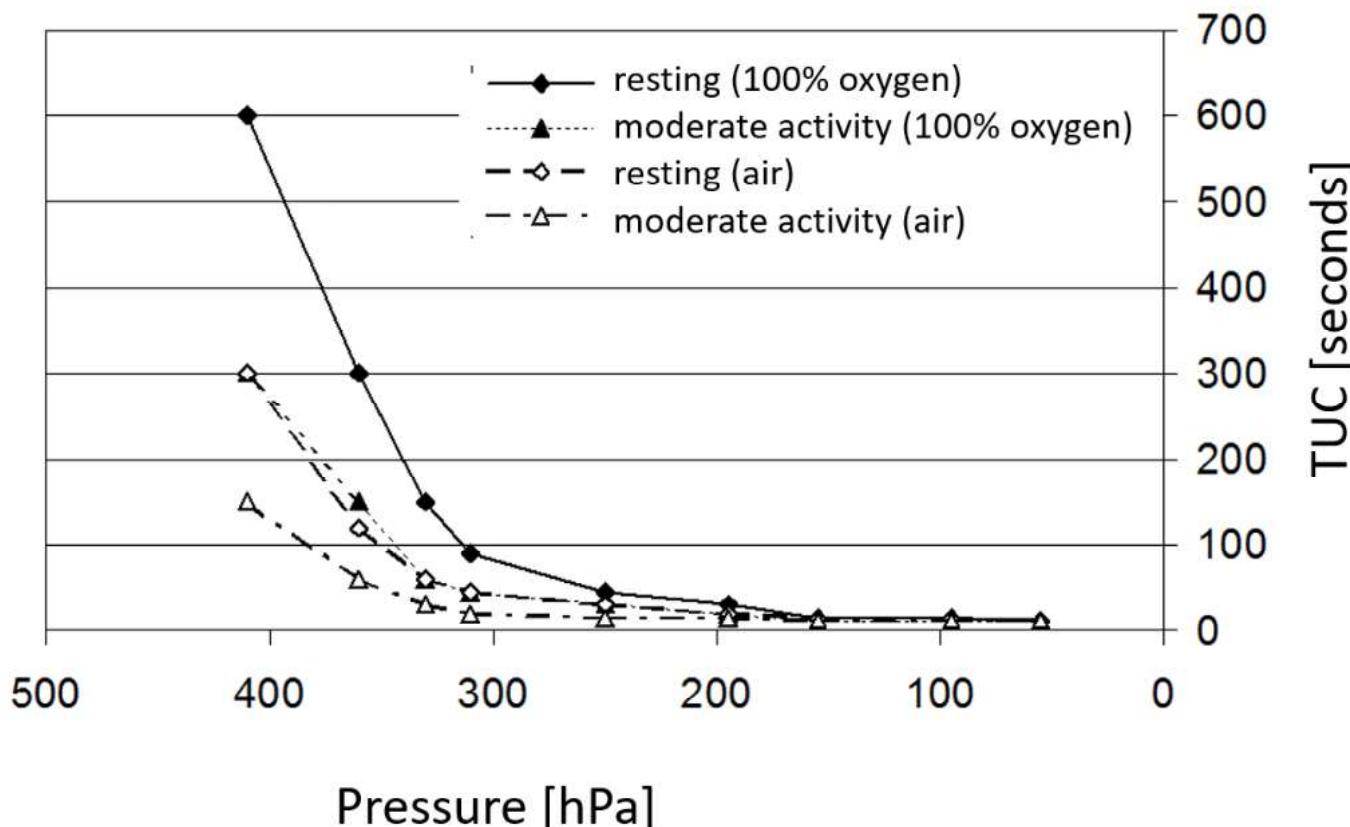
Factors of influence

- P_{O_2} , Temperature, Blood pH
- Environmental
 - age, cardiovascular and respiratory diseases...

Accidental decompression

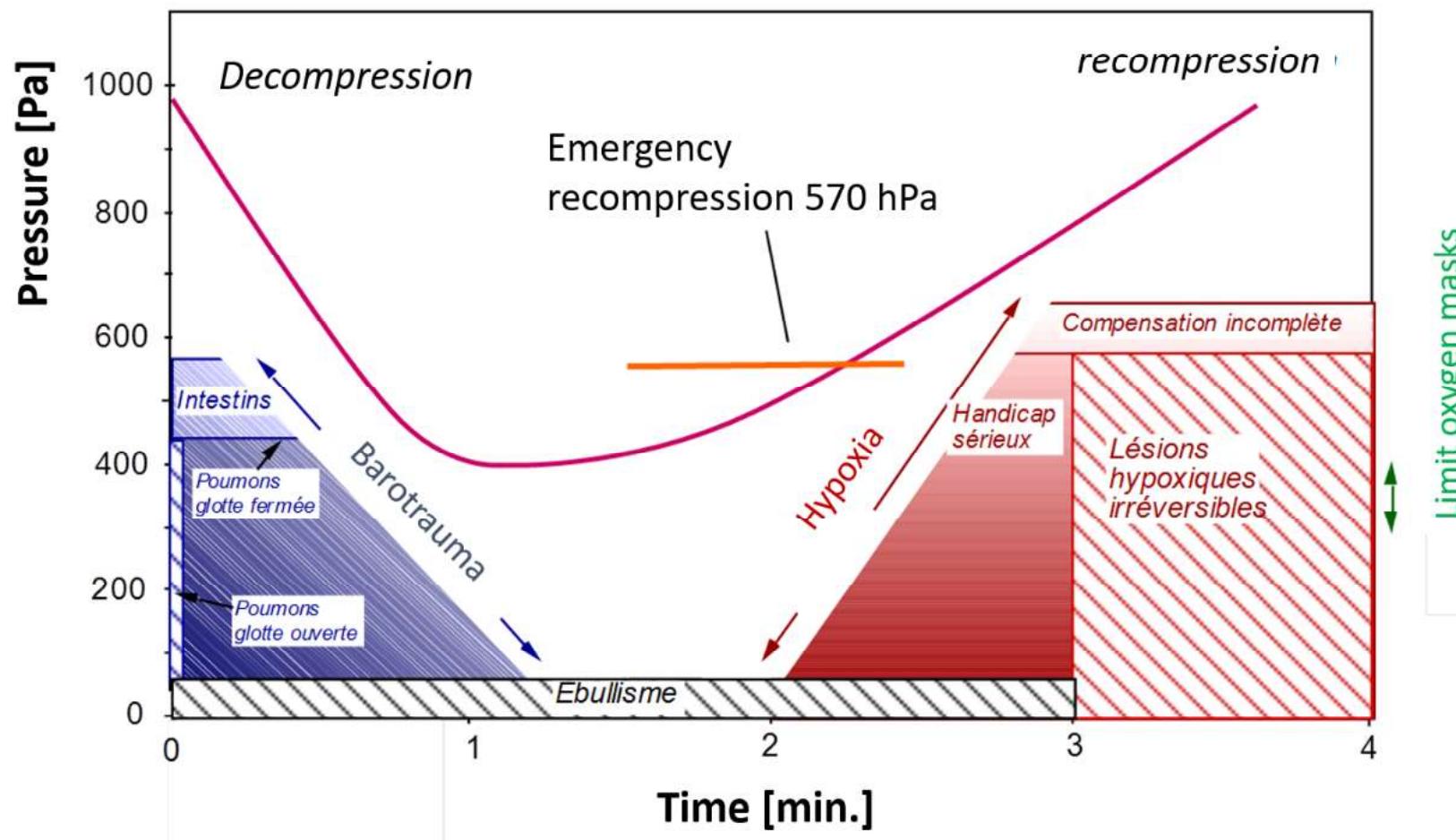
The time of useful consciousness

- Ability to initiate rescue actions
 - for rapid decompression < 30 s



Accidental decompression

decompression and emergency recompression



Ebullism (hypobaric environment only)

Ebullism

- Extreme hypobaric environment (aerospace)
- Vapor pressure of water at 37 °C = 63 hPa
- Blood boils

Characteristics

- Absolute pressure
- Snapshot

Prevention

- Rester sur la terre ferme

Confined spaces

Confined space

- Totally or partially closed volume
 - low air exchange, not a working space

Hazard

- **Hypoxia**, intoxication, explosion

Prevention

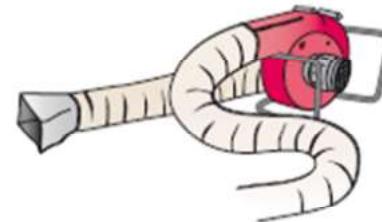
- Wells, pits, sewers, tanks, vats (fermentation tanks), silos...



Confined spaces

Preventive measures

- Ventilation of the space
 - mechanical, natural drafts
- Removal of indoor pollution sources
 - e.g. combustion engine
- Air quality monitoring
 - oxygen measurement, other pollutants
- Personal protection
 - self-contained breathing apparatus (SCBA)
- Training, instruction
 - intervention, rescue (over-accident)



Confined spaces

- Requirements for pits and pipelines

(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	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 pompes, puisards à pompes d'eaux souterraines	Bassins de décantation, installations de décomposition, ouvrages destinés au traitement des boues de curage	Canalisations étroites destinées au transport de l'énergie et aux télécommunications
Mesures				
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 puisards 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 respiratoire isolant de secours sur l'homme (F) (chiffre 4.6/6.4)	F ³⁾			
Assurer la surveillance 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 liquid nitrogen produces ~0.7 m³ of nitrogen gas (odorless and invisible)
- Lowering of the oxygen content by dilution

Sectors involved

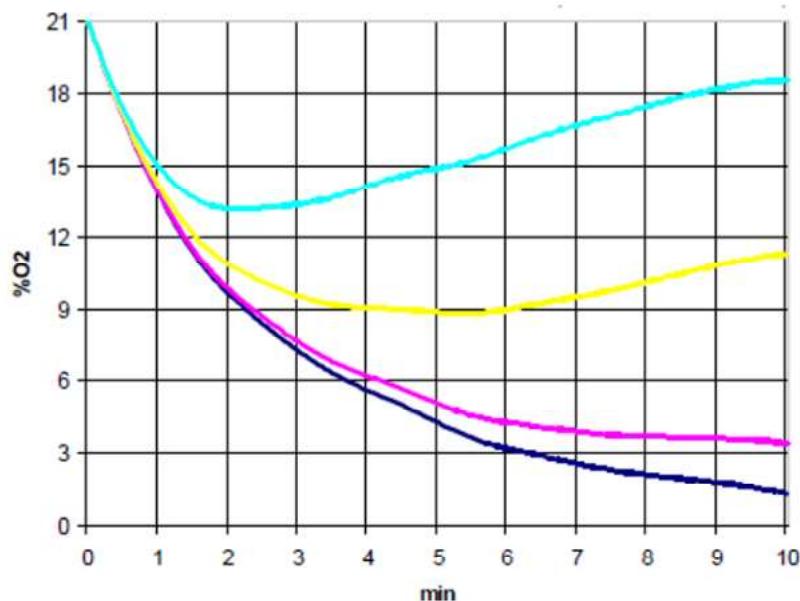
- Superconductivity physics laboratories
- Biology and medicine sample conservation
- Food
- Rapid freezing

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

Cryogenic liquids

Example

- Liquid nitrogen in laboratories for medically assisted reproduction
 - cold storage, levelling of storage/warehouse
 - "normal" evaporation and accidental situations



Oxygen level in a 30 m³ room during chilling
(Afset 2008)

Lowering of the oxygen content

Sectors involved

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

