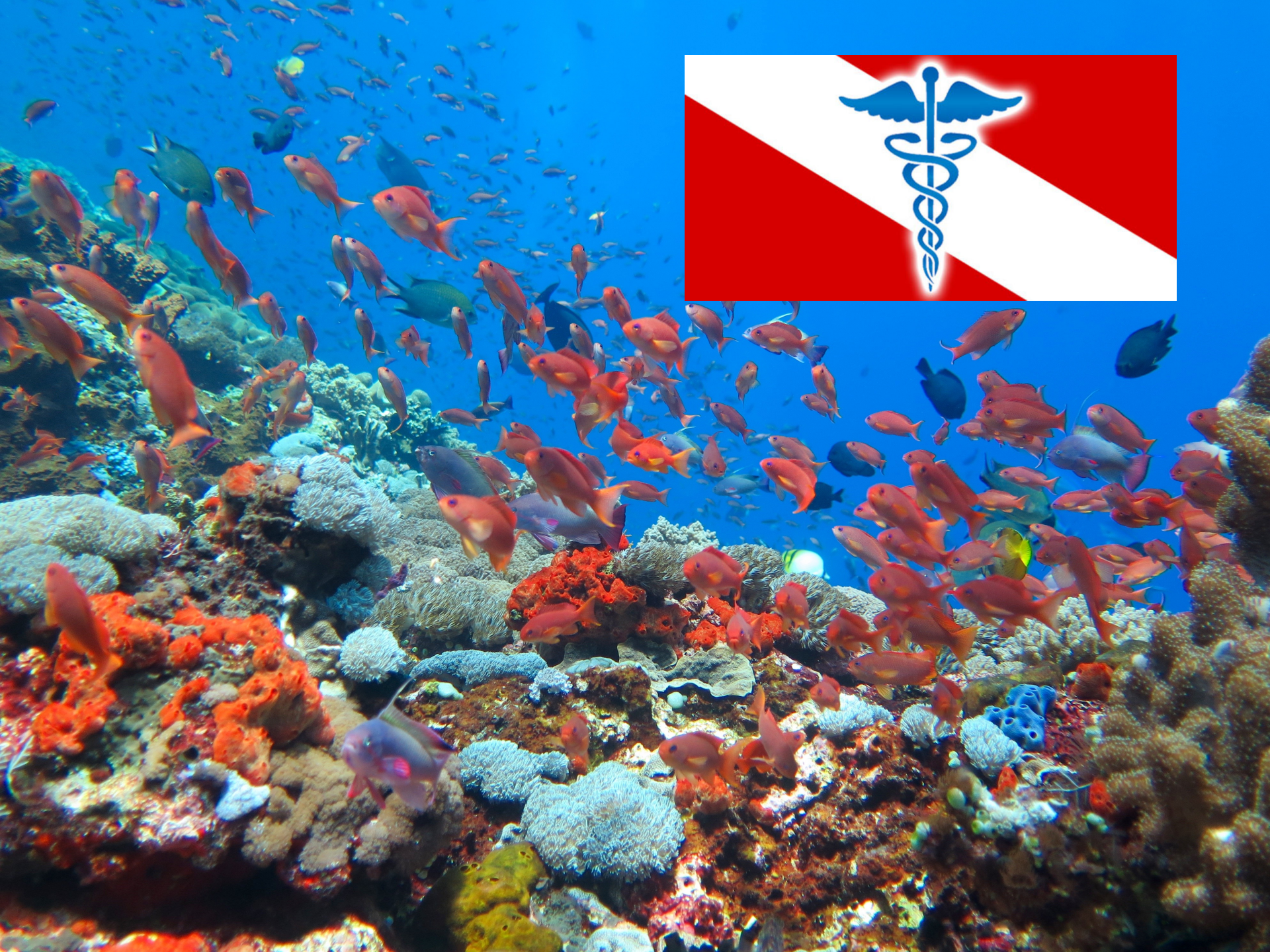
Diving Medicine and Emergencies



Diving Medicine and Emergencies

UCSF

Wilderness

Medicine

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Emergency Medicine
ZSFGH

May 10, 2017

" Prepare to dive... "

What we won't talk about...

Conditions *NOT* acutely related to direct water pressure, or breathing compressed gases:

- Motion Sickness
- Near Drowning (or drowning)
- Hypothermia
- Physical Trauma
- Hazardous Marine Life
- Infectious Illnesses
- Chronic illnesses related to diving

What we WILL talk about...

Diving physics, physiology: barotrauma, breathing compressed gases, dissolved gases, …and the consequences

- Barotrauma – injury caused by direct pressure:
  - Ear injury, “squeeze” (and expansion) syndromes
- Conditions caused by breathing compressed gases:
  - Pulmonary “overpressure” incidents
  - Arterial Gas Embolism
- Conditions caused by breathing dissolved gases
  - Decompression Sickness, e.g. “The Bends”
  - Neurological emergencies related to diving
  - Nitrogen narcosis, oxygen toxicity

Case # 1

- You are an RN in the Triage area of a small E.D. in Utah. It's mid-afternoon.
- A young man comes to the Triage Area c/o the feeling that his balance is "off", and he has some odd tingling in his extremities. He says his speech is slightly affected. ***" Whaat? "***
- You ask about trauma, weakness, ear infection symptoms, and headache (none are present)…
- In your careful triage assessment,

you enquire about his recent activities…

Case # 1, continued

- He says, "…oh, yeah… we just got back from a great vacation in the Caribbean…"
- You, the astute RN, working 3,700 miles distant from the patient's vacation destination…

wonder… (hmm?)

You ask… "_____(fill in)_____?"

A very short history of diving …

Greek free divers – over 1000s of years

The ancient view of diving history

- The earliest divers were “free divers” - ? Greece

The long view of diving history

- The earliest divers were “free divers” - ? Greece
- The ‘Ama’ (Japan) - over 2,000 years history.
- Classical Greek and Roman times:

  Military and commercial diving appears.
- 16th and 17th Centuries – diving bells developed.
- 18th century: surface-supplied diving helmets.
- **Mid-20th century: open and closed SCUBA**
- Later 20th century: many advances:

  Heliox, saturation diving, underwater habitats, more…

The long view of diving history

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The long view of diving history

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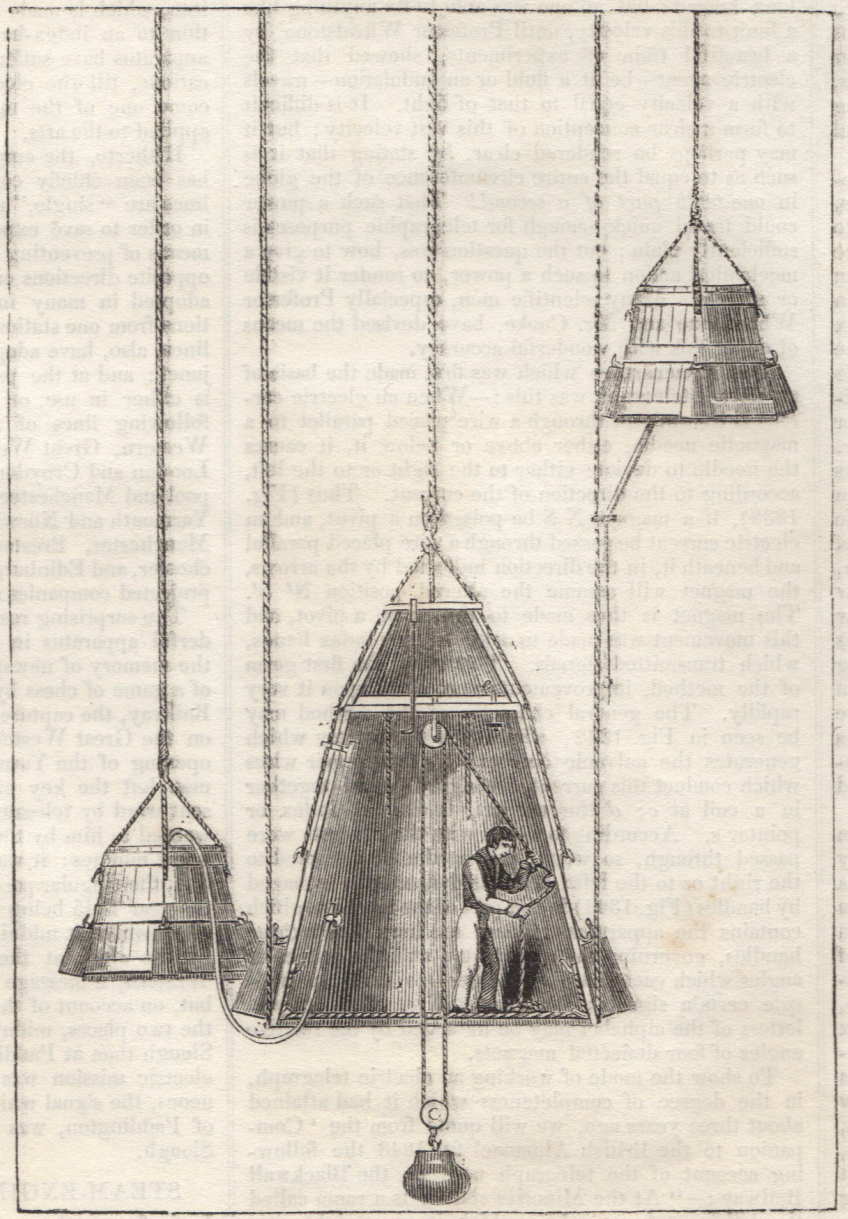
Military and commercial diving appears

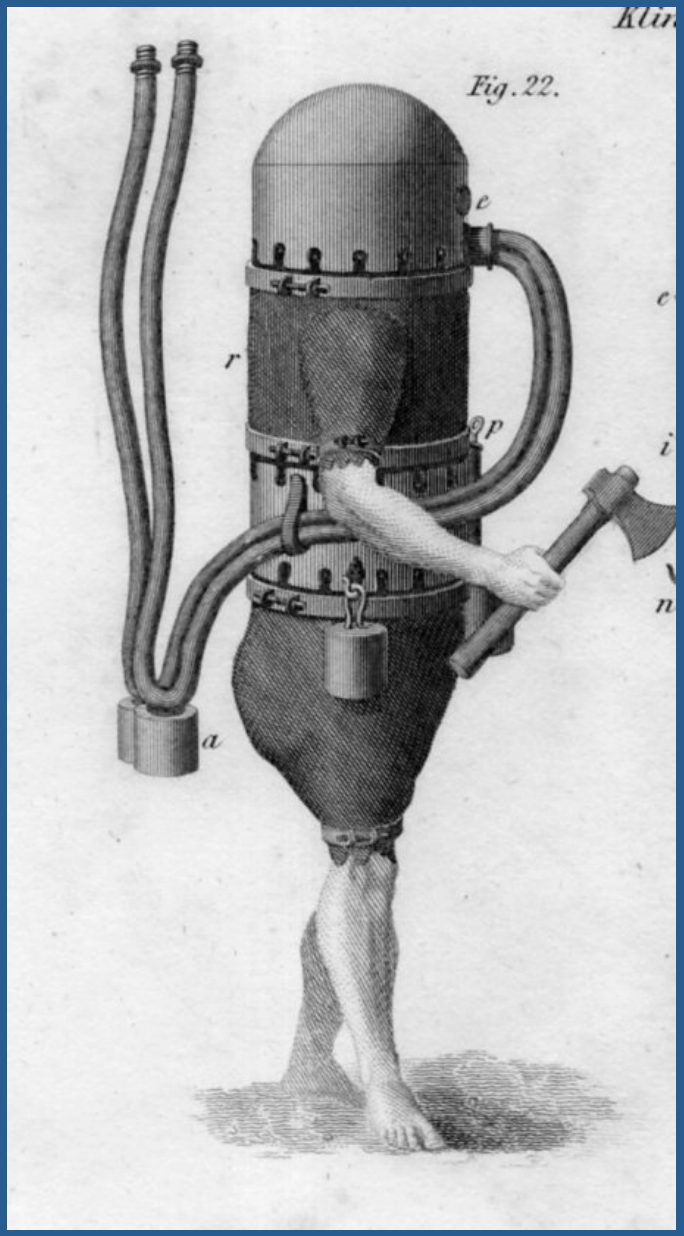
Alexander the Great
ca. 1600

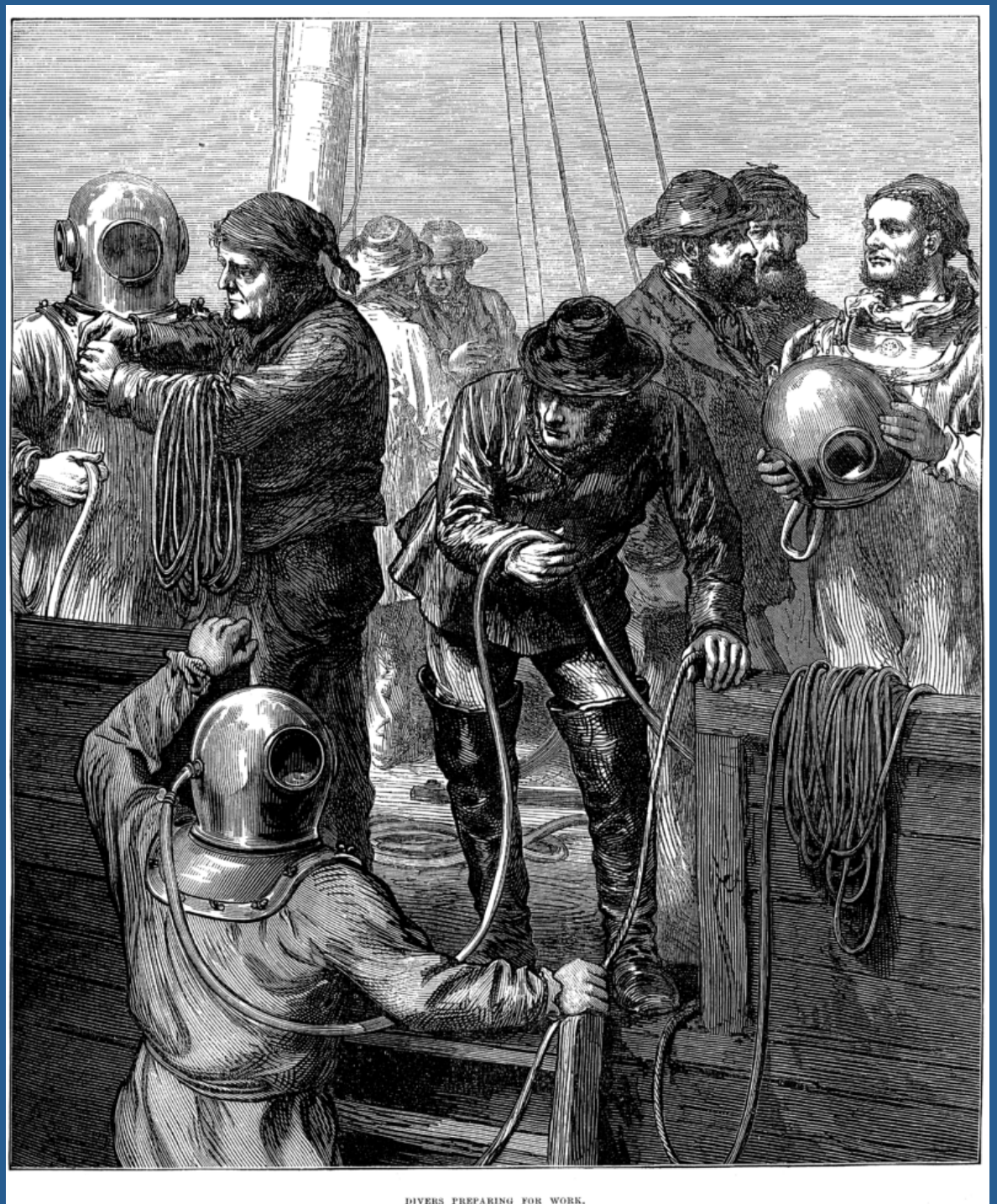


1353.—Diving-Bell, on Spalding's arrangement.

Diving Bell, 1980

Transition from bells, to “hard hat” diving

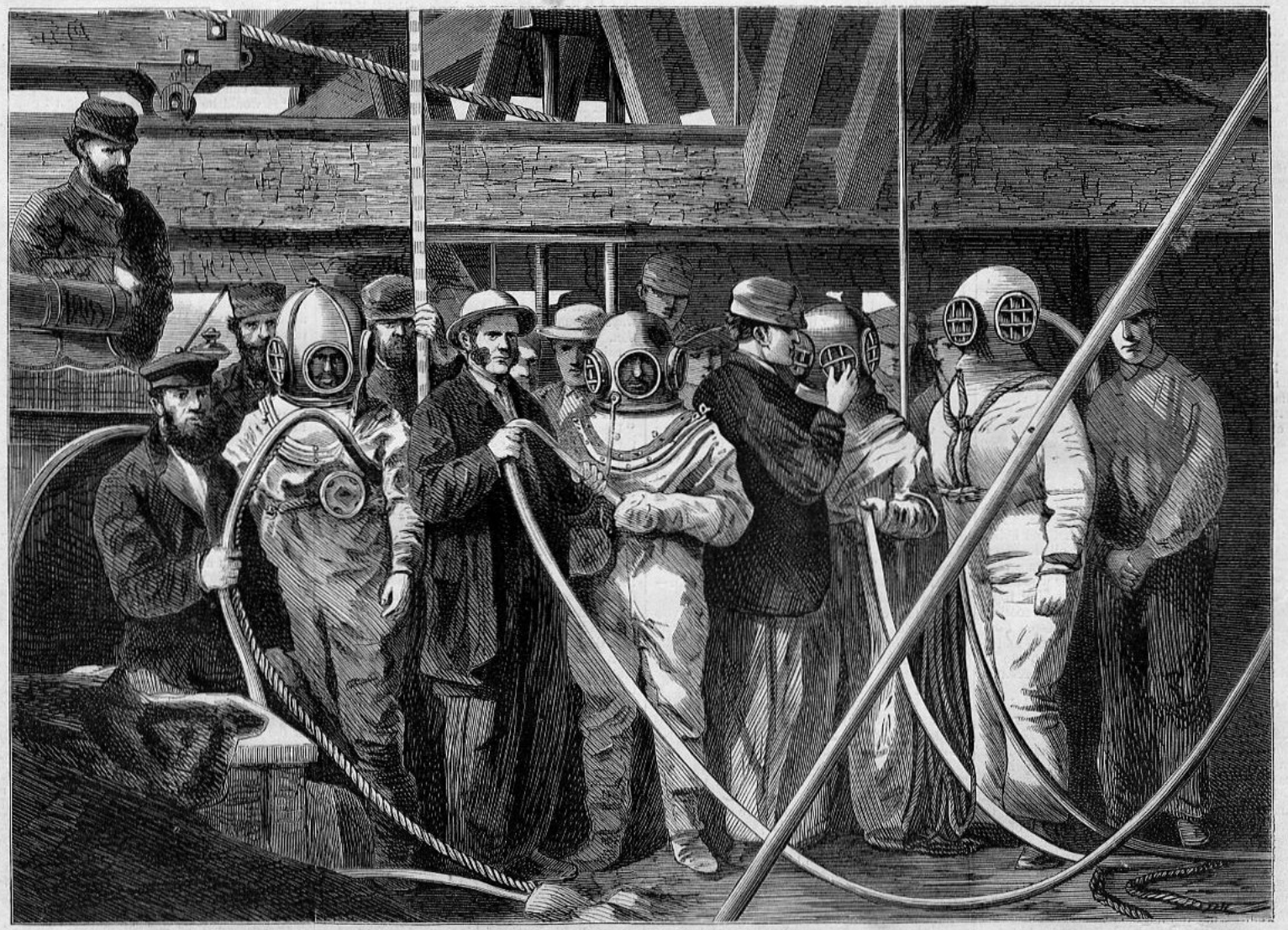




DIVERS PREPARING FOR WORK.

Siebe's Improved Design (1837)

From early 1800s, to between the Wars: Salvage, Exploration, Treasure, Construction



SUBMARINE DIVERS EQUIPPED FOR THEIR DESCENT.—[See Page 295.]

Diving on the Lusitania in 1925 (sunk in 1915)

The long view of diving history

- The earliest divers were “free divers” - ? Greece
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- Early 20th century: open and closed SCUBA
- **Later 20th century: many advances:**

  Heliox, saturation diving, underwater habitats, more…

Long-term “saturation” habitats

The modern era: SCUBA

Self - **C**ontained **U**nderwater **B**reathing **A**pparatus

Jacques-Yves Cousteau

The traditional “2-hose” regulator

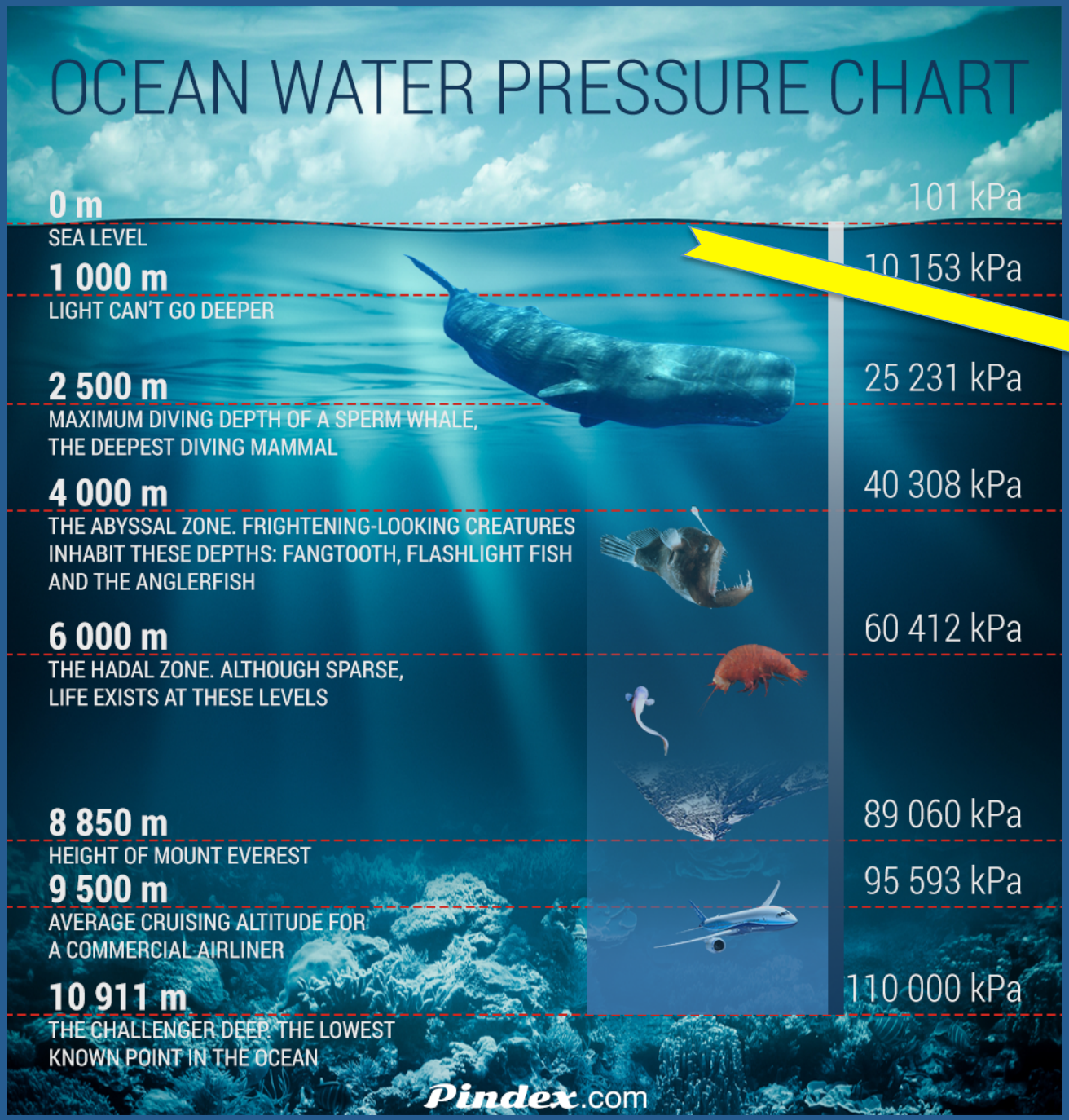
SCUBA moved to single-hose regulators

Advantage: the final pressure-regulator occurs right at the mouth, closest to the level of the lungs.

The early gear – now vintage

The Physics of Diving

* simplified *



The Big Picture

Snorkeling
- surface – 10 ft.

Serious snorkeling
- to 20 ft.

"Free diving"
- to 100 ft. +

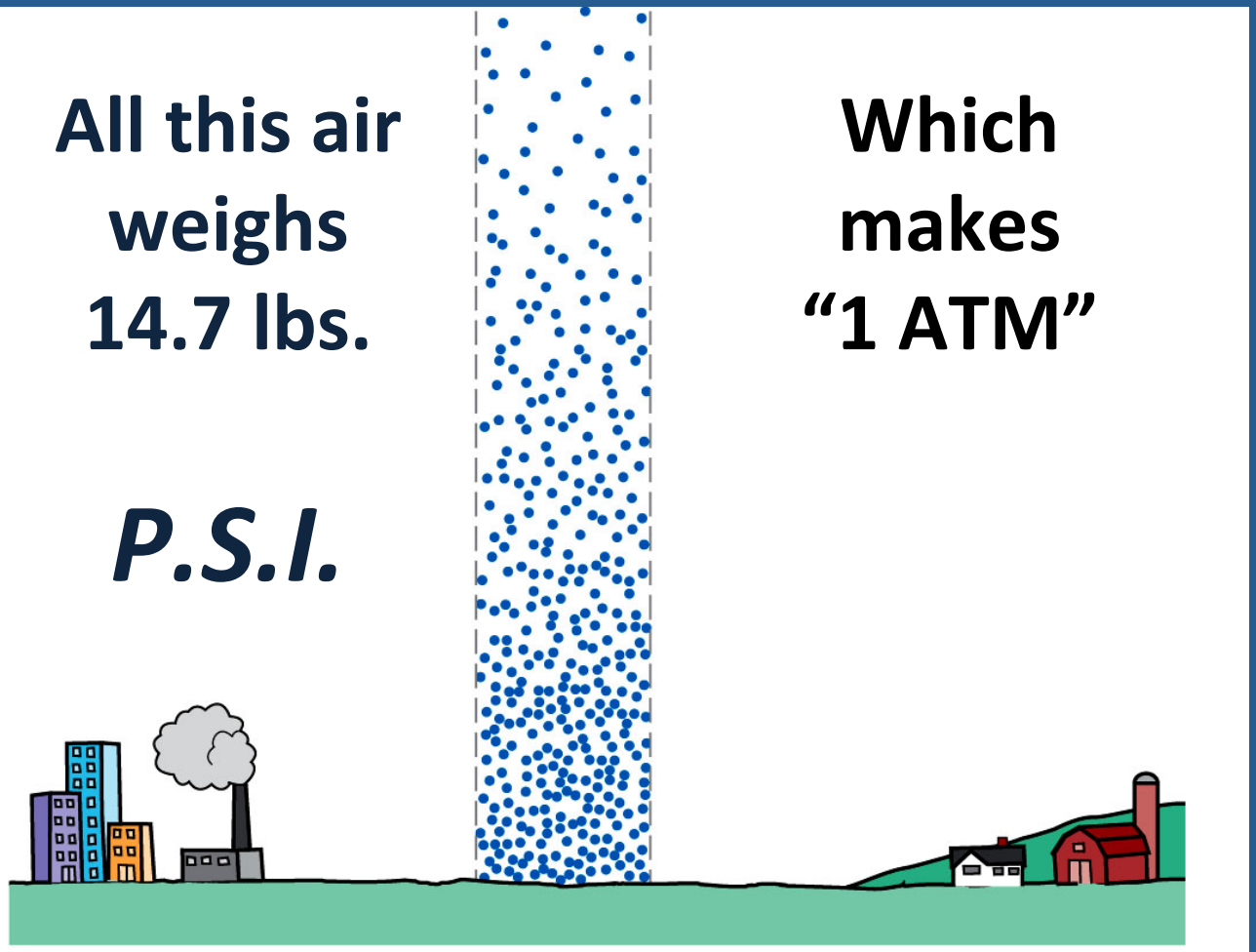
SCUBA
"maybe" 130 ft.

Specialized gases
Habitats
Research

What is “One Atmosphere”?

All this air weighs 14.7 lbs.

P.S.I.

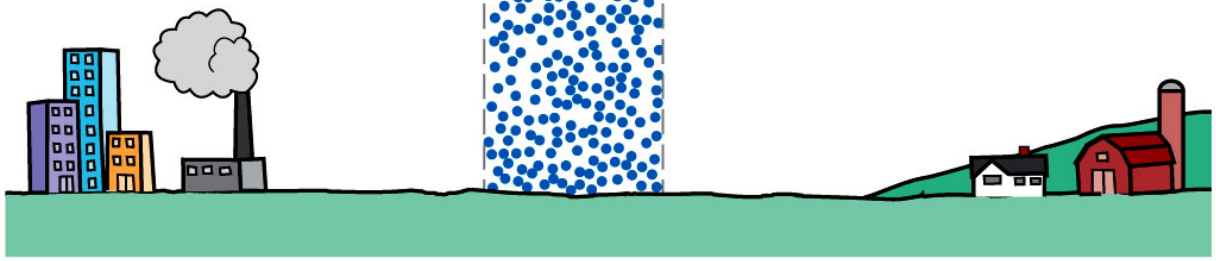


Which makes “1 ATM”

What is “One Atmosphere”?

All this air weighs 14.7 lbs.

P.S.I.



Which makes “1 ATM”

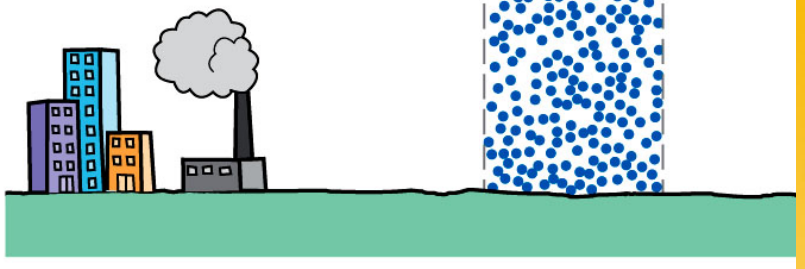
But:

What about the water below??

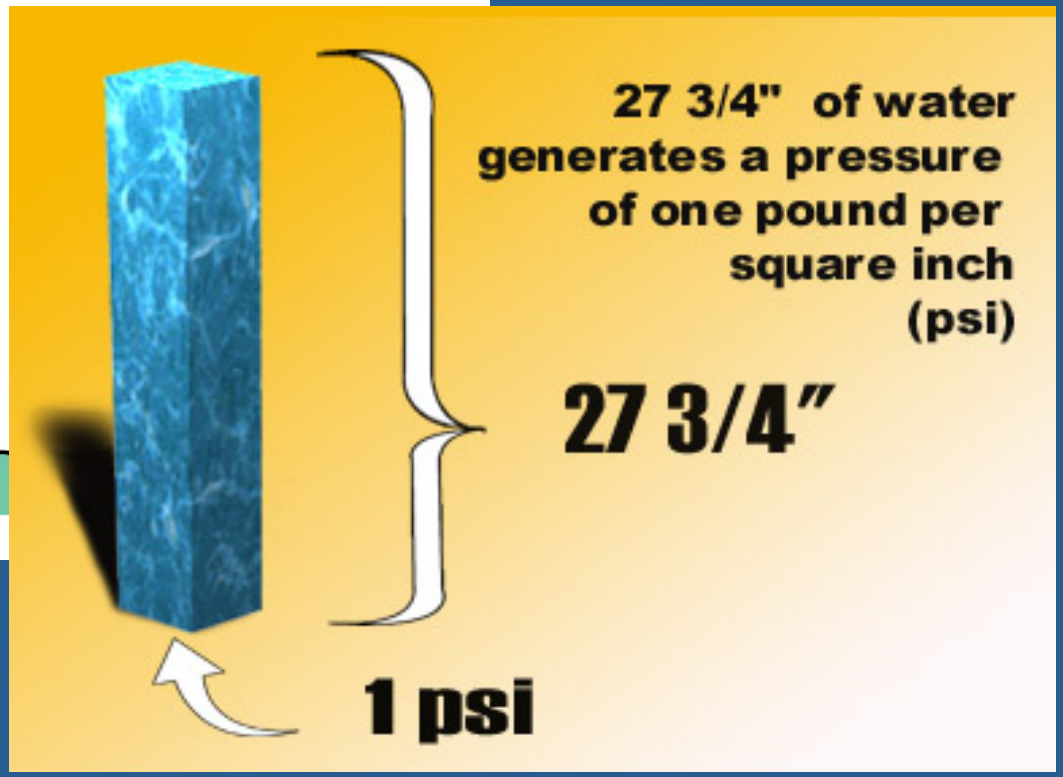
What is “One Atmosphere”?

All this air weighs 14.7 lbs.

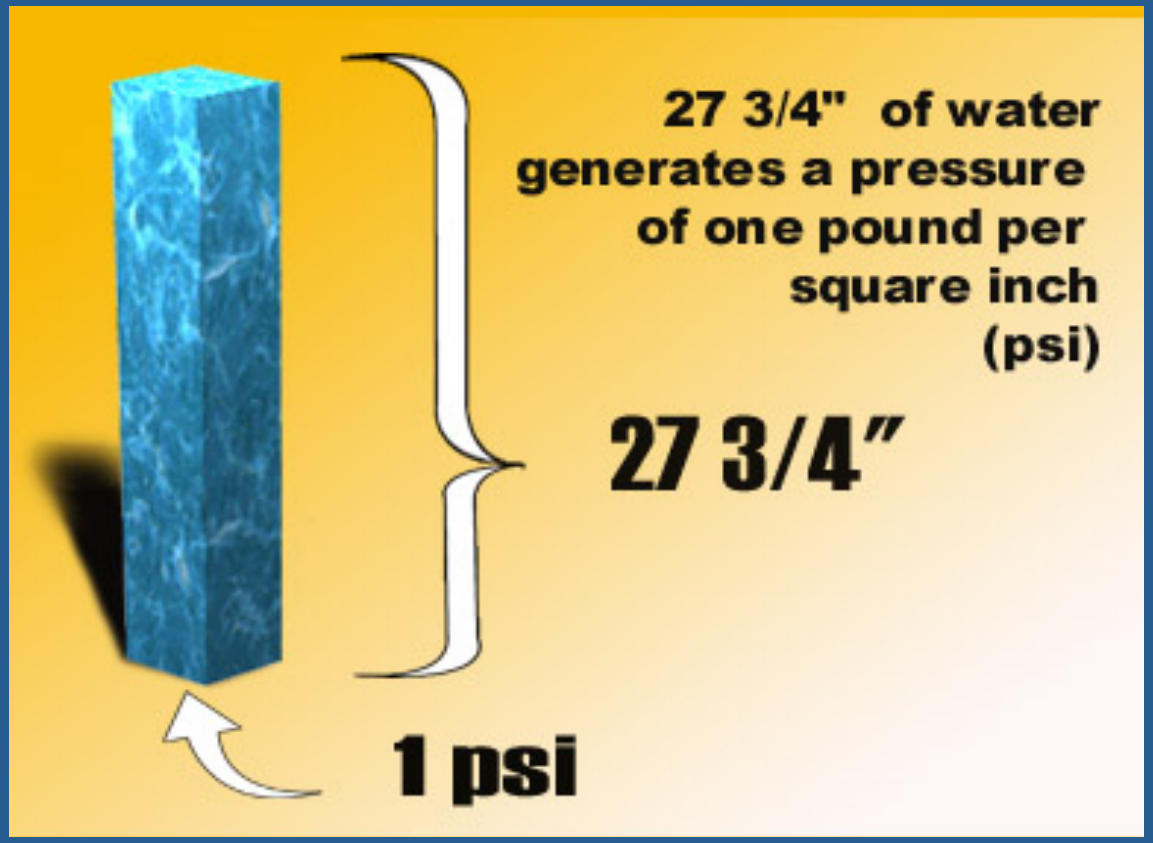
P.S.I.



Which makes “1 ATM”



So, what is the undersea "One Atmosphere" pressure equivalent ?



If

1 P.S.I. ≈ 27-3/4"

then

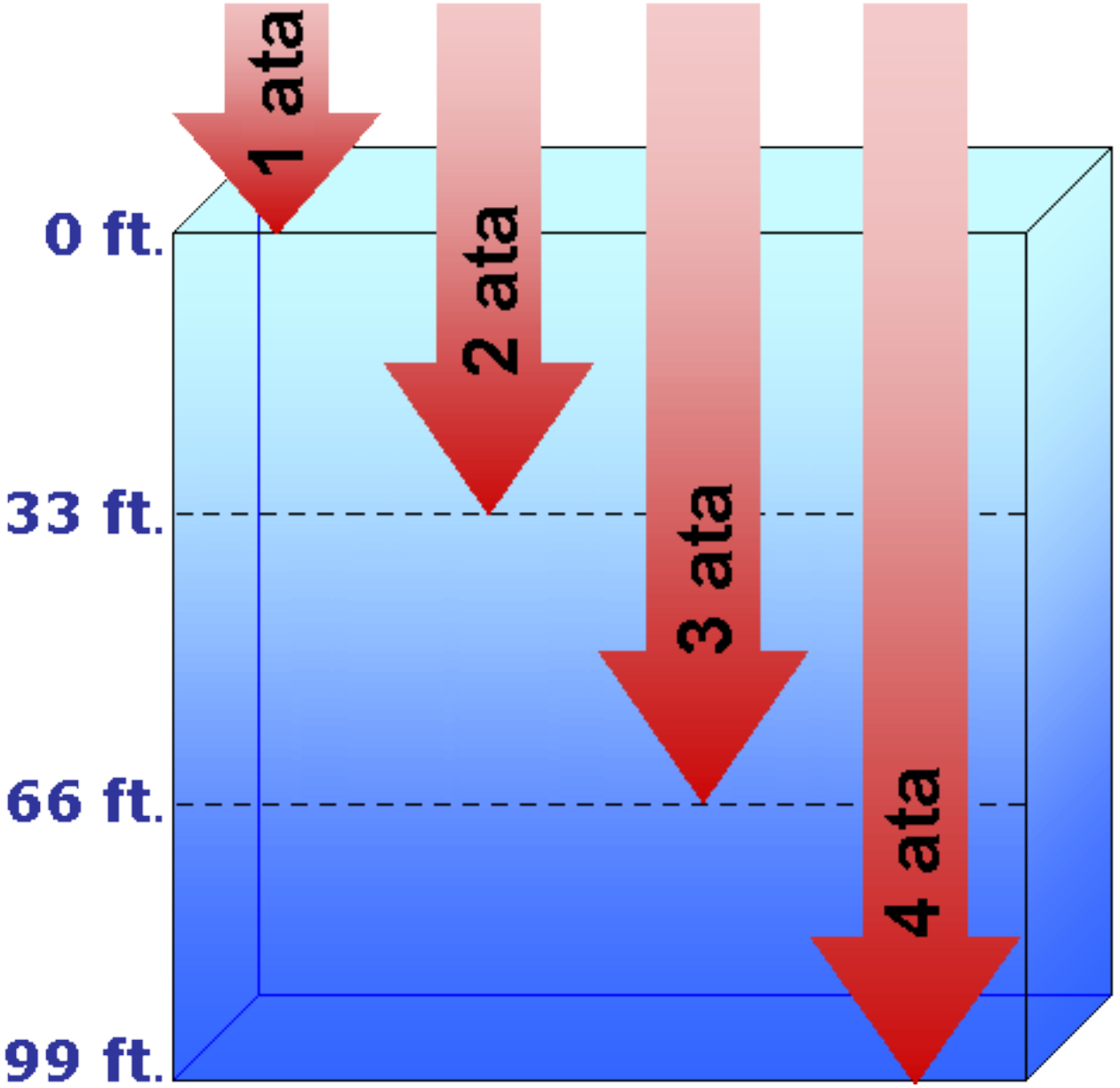
14.7 P.S.I. ≈ 400"

or, about

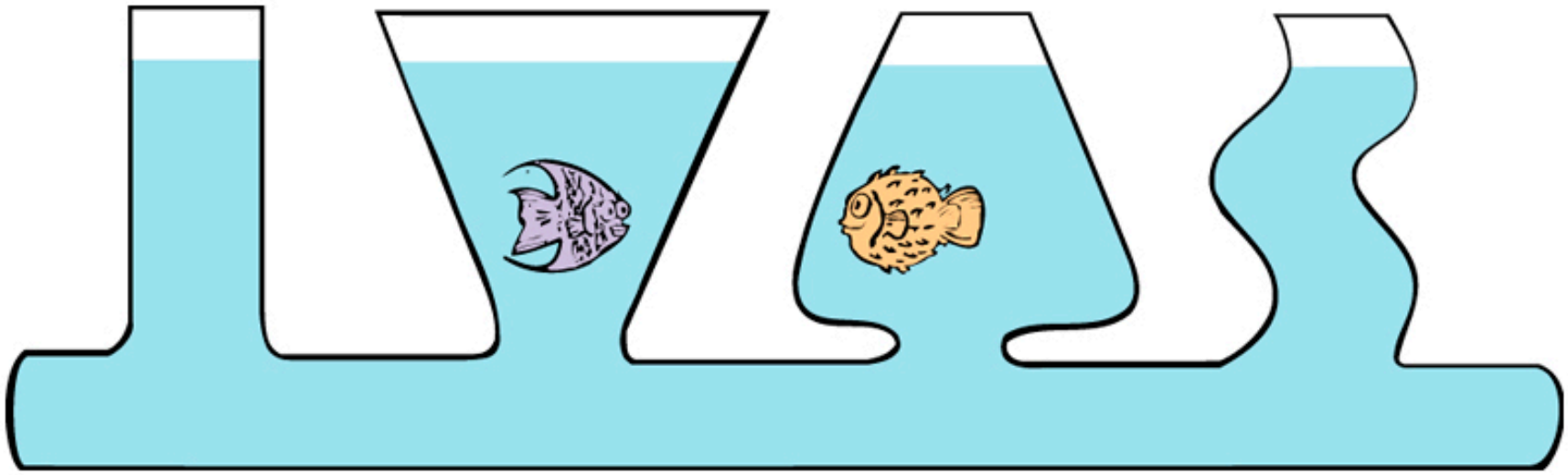
33 ft.

(the magic number)

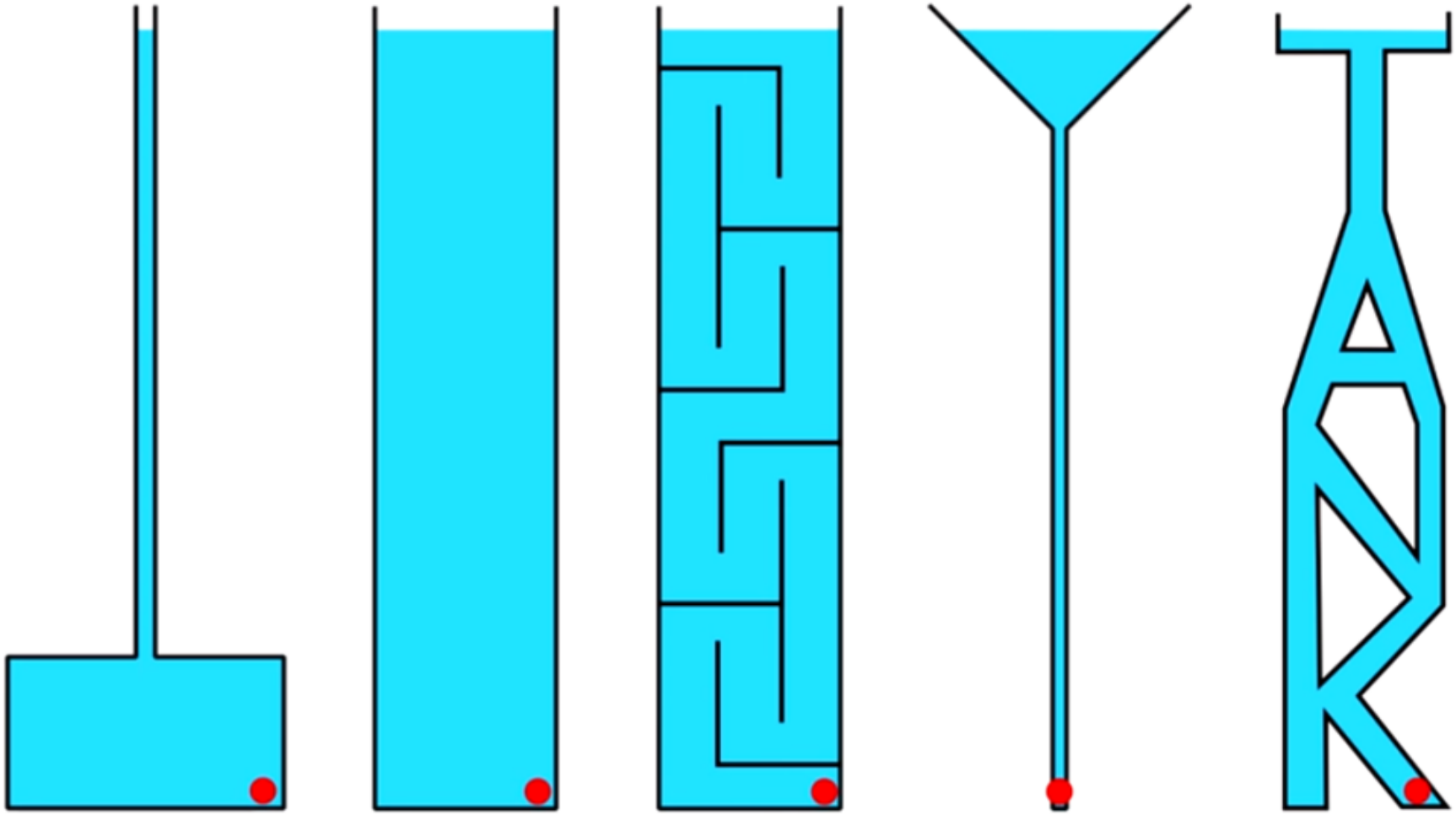
One “atmosphere” for each 33 ft. depth



Key Concept:
Water pressure depends ONLY on depth, not on the shape of the water column above it



“Pounds per square inch”…
or number of “Atmospheres”…
It’s always about depth.



More Key Concepts

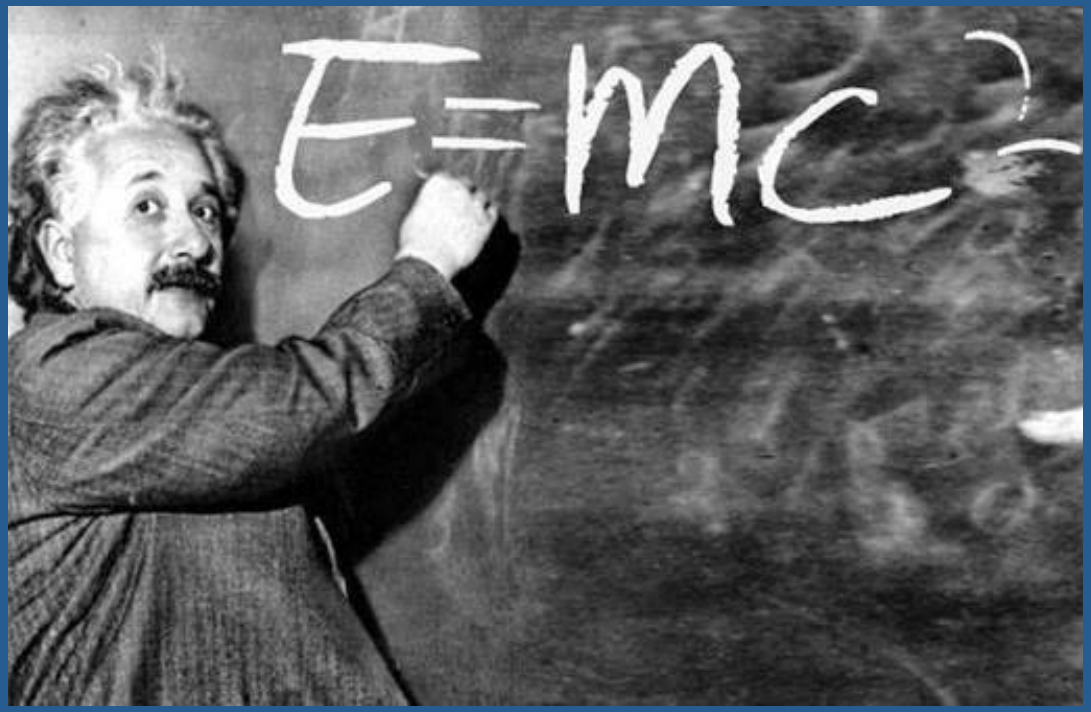
- Air is compressible.
- Water is essentially incompressible.
- So, *all* air-containing structures get compressed, in proportion to depth.

Now, the “ Laws of Diving ”

- Ideal Gas Law
- Boyle’s Law
- Dalton’s Law
- Henry’s Law

* and, last but not least: ***Murphy’s Law***

The Ideal Gas Law:
a.k.a. – what I learned in college



The Ideal Gas Law:
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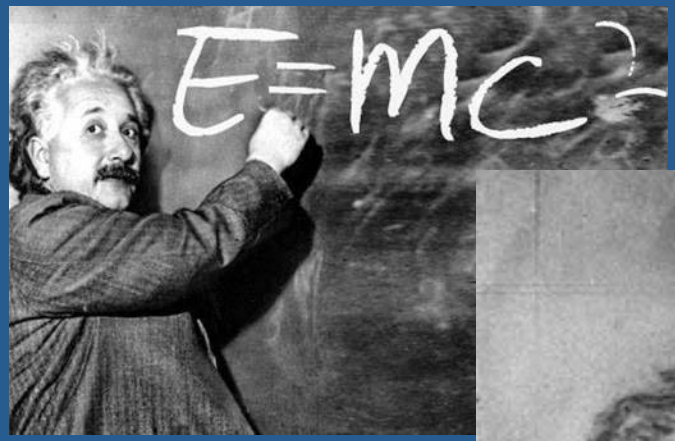
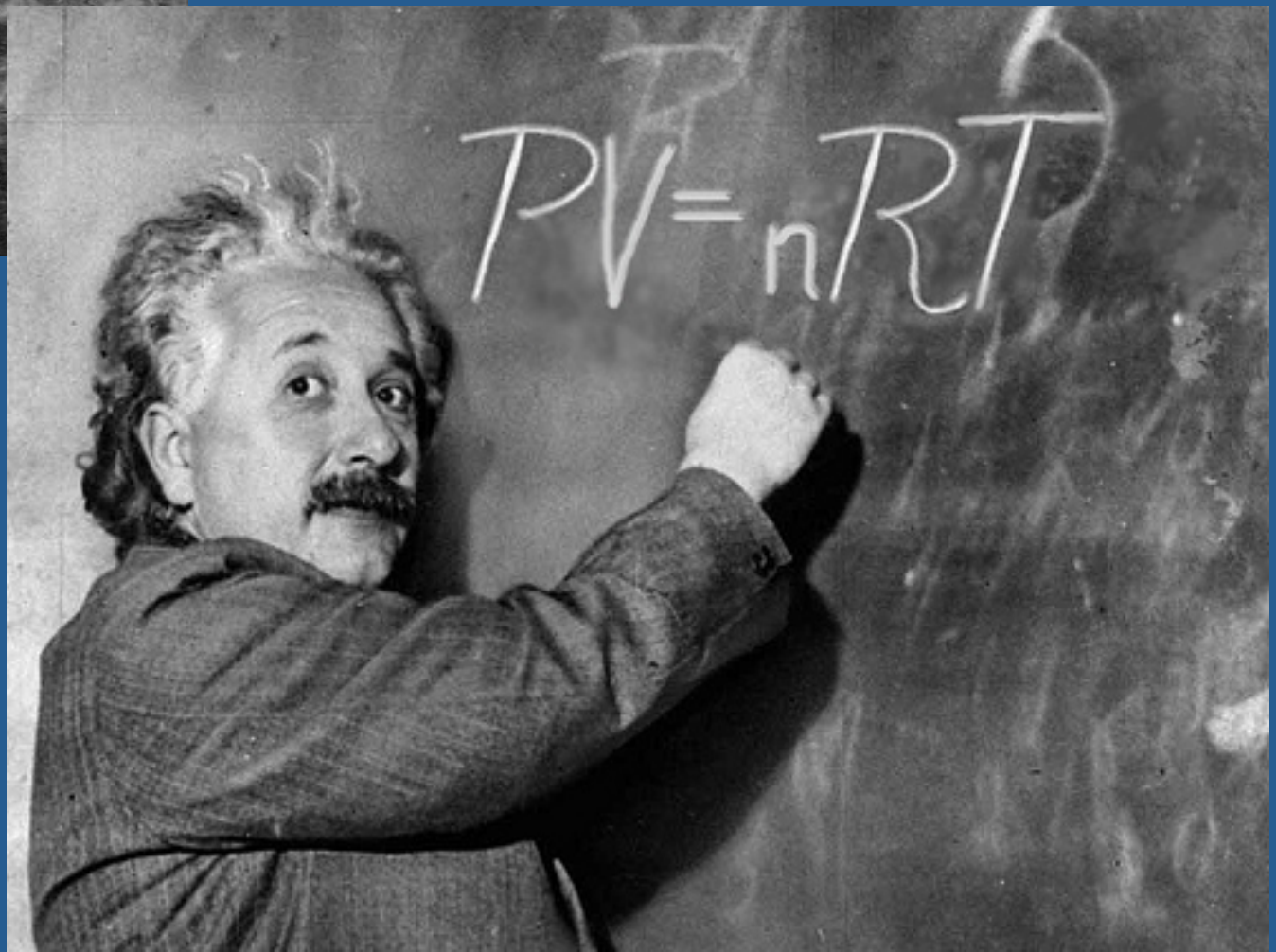




P x ***V***

Equals

n x ***R*** x ***T***

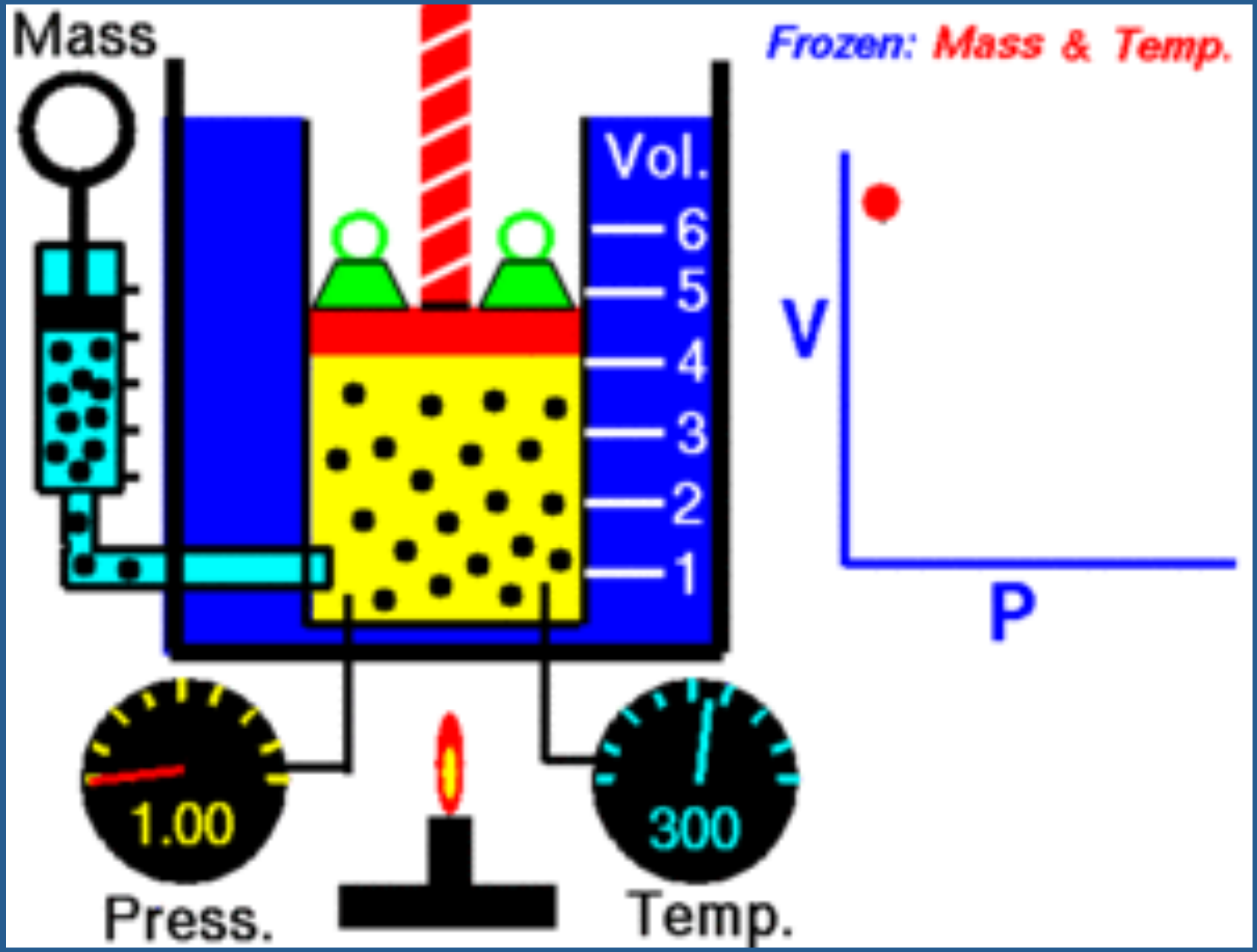
The " Ideal Gas Law "

PV = nRT

- P = pressure
- V = volume
- "n" = "number"
  - the ***amount*** of gas molecules (mass)
- "R" = the "mathematical constant" – uggh
- T = temperature (we will not consider)

Start by considering just Pressure x Volume

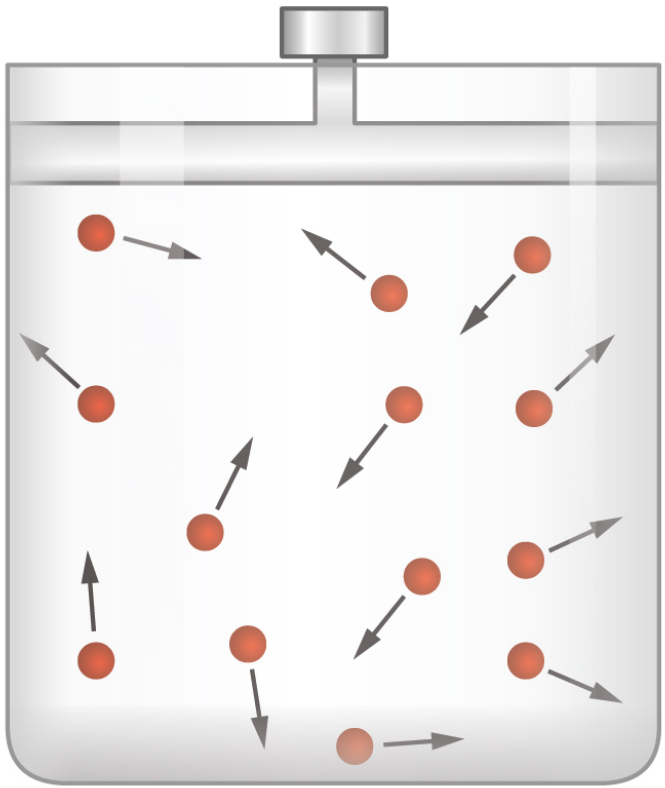
$PV = nRT$



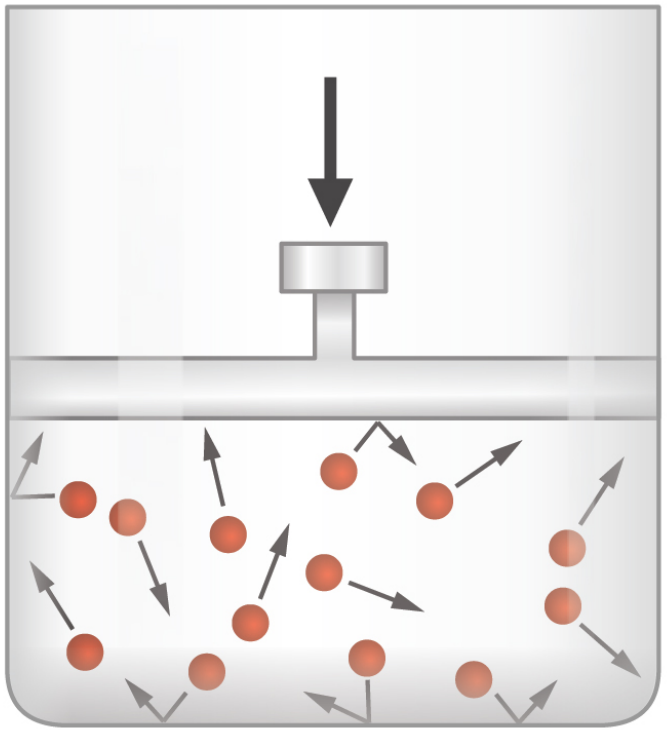
Boyle's Law: $P_1 \times V_1 = P_2 \times V_2$

Pub. 1666

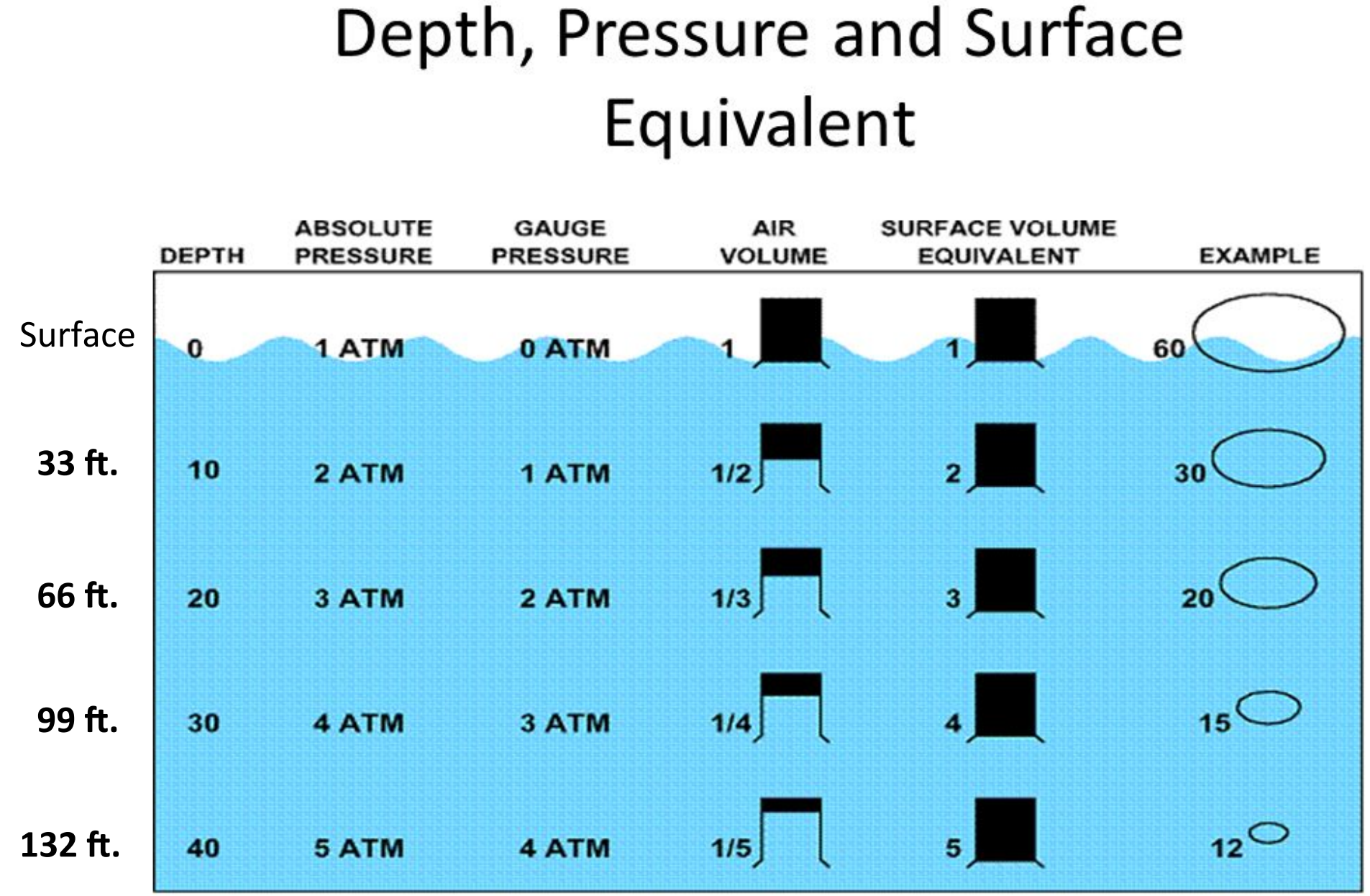
As volume increases, pressure decreases



As volume decreases, pressure increases



Boyle's Law – the picture says it all



Types of “simple” barotrauma

- “Mask squeeze”
- Ear injury – eardrum rupture,
  - “round or oval” window rupture
  - dis-equilibrium and spatial disorientation
- “Sinus squeeze”
- Dental “squeeze” or expansion
- Intestinal “expansion”/perforation

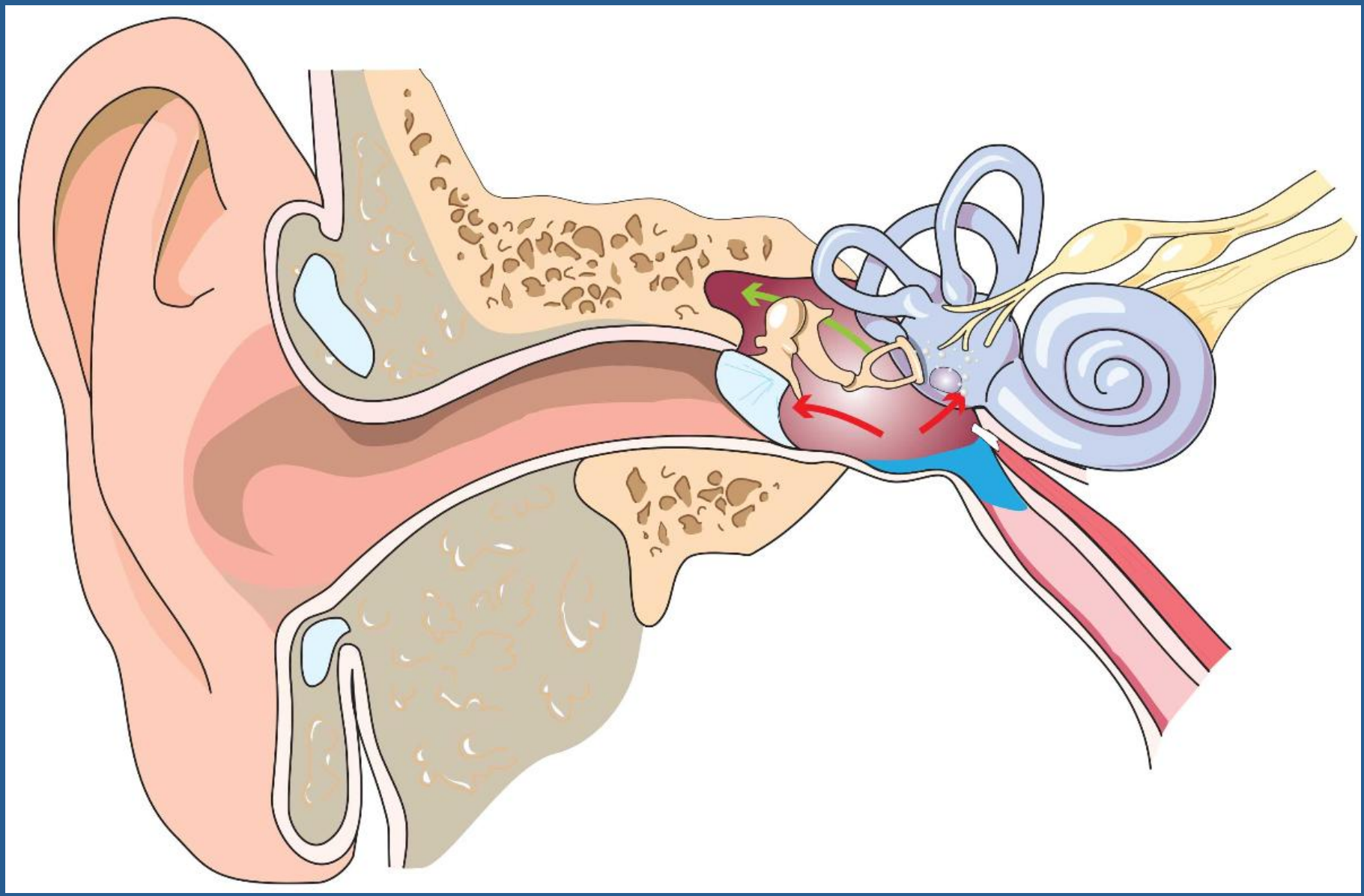
“Mask Squeeze”

To avoid:

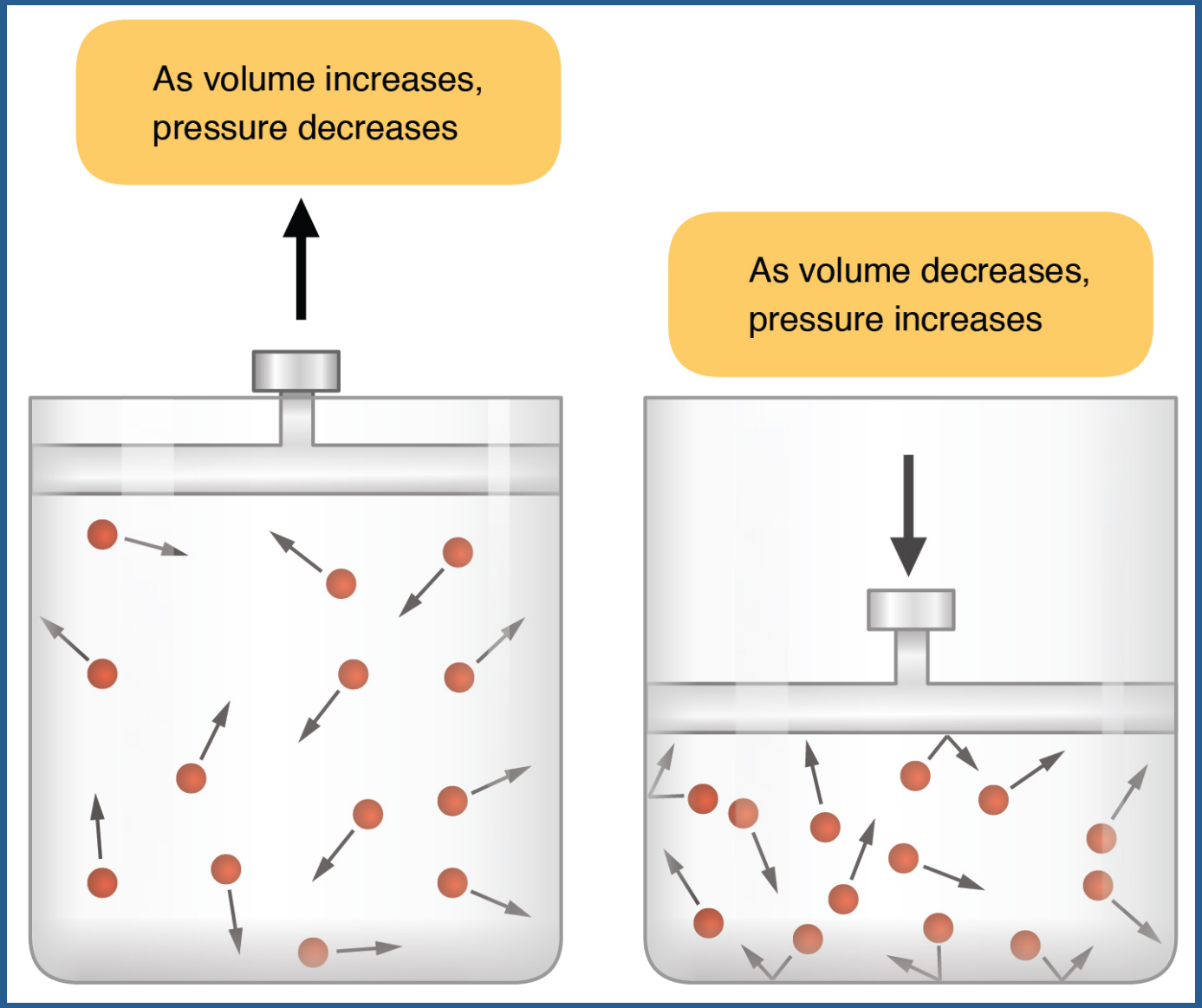
“Vent” your oral air (pressure) through your nose into your mask.

"My ear is hurting" – can't 'equalize'

Tympanic Membrane: ***Must equilibrate !***



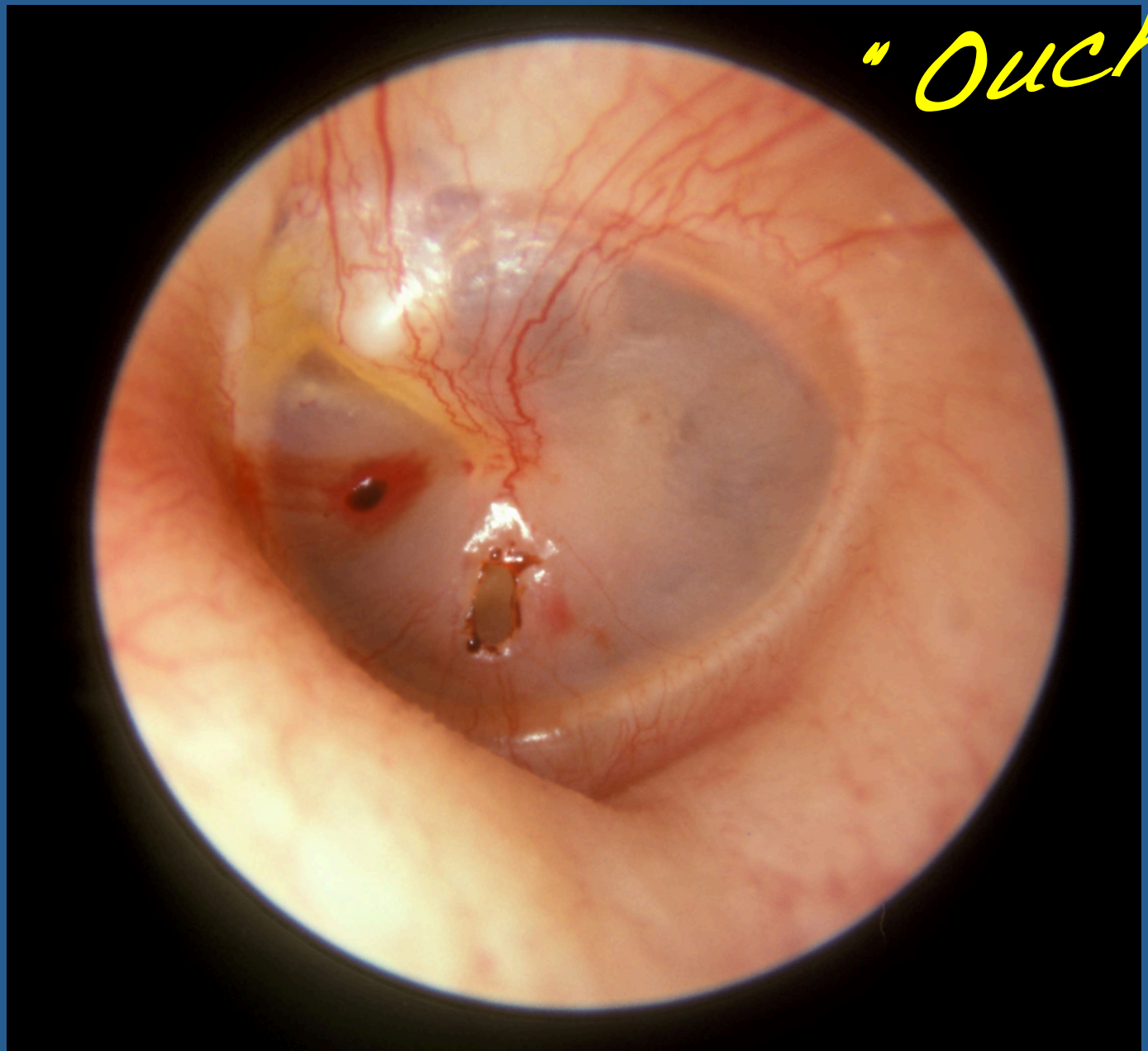
Remember Boyle's Law: $P_1 \times V_1 = P_2 \times V_2$



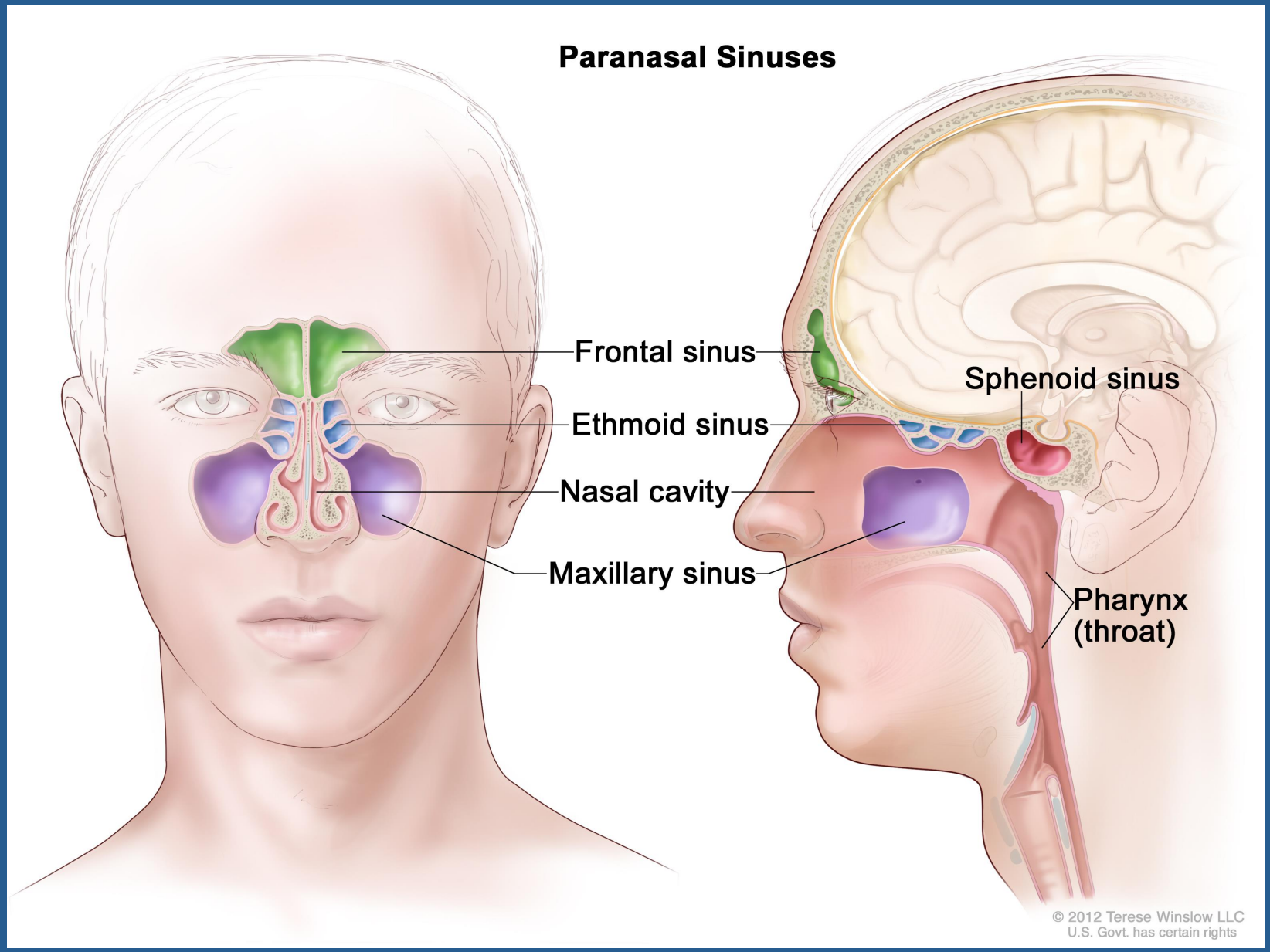
Send some of this ***pressurized air*** into your Eustachian tubes.

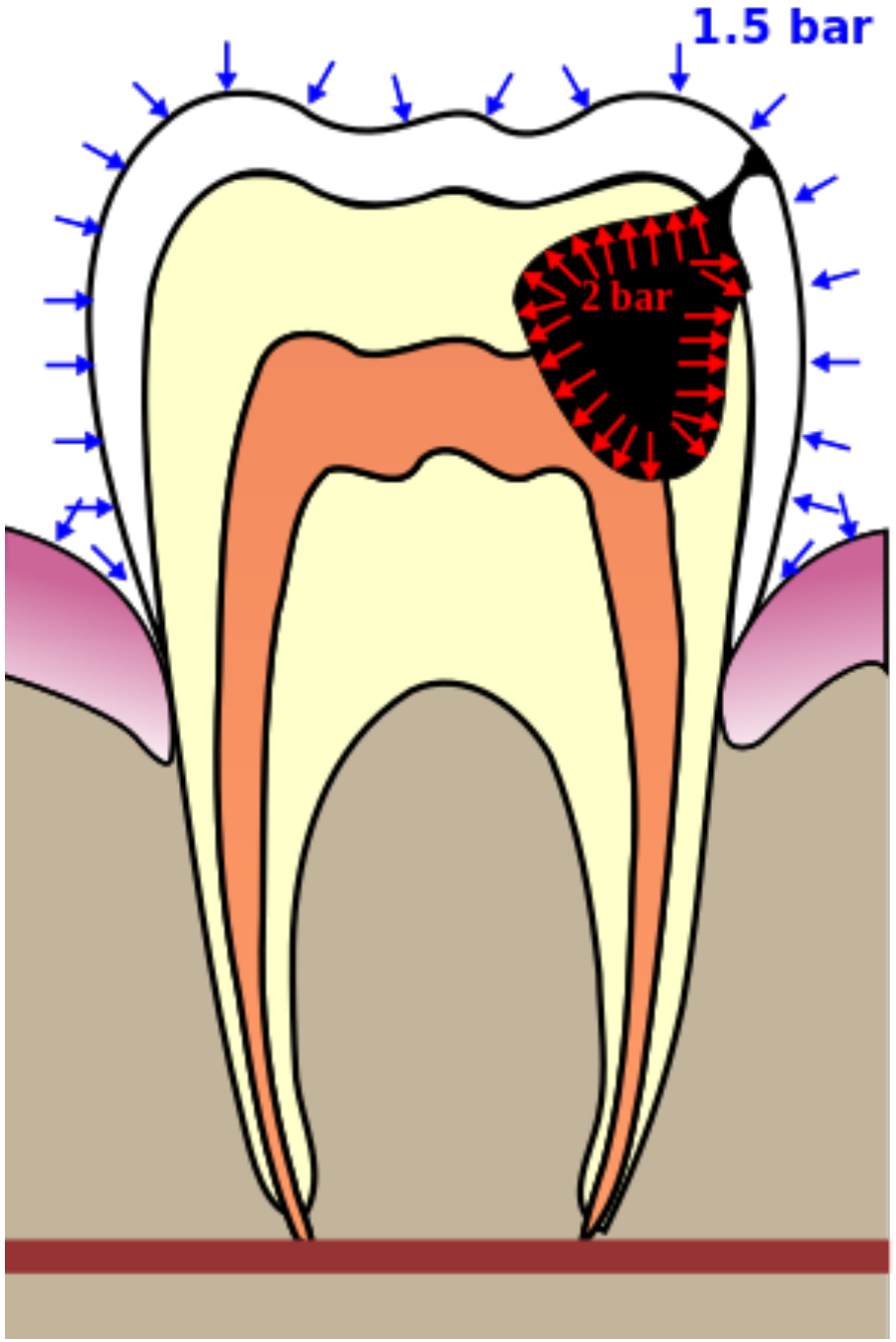
Balance pressure on both sides of your TM.

Perforation of the eardrum



“Sinus Squeeze”

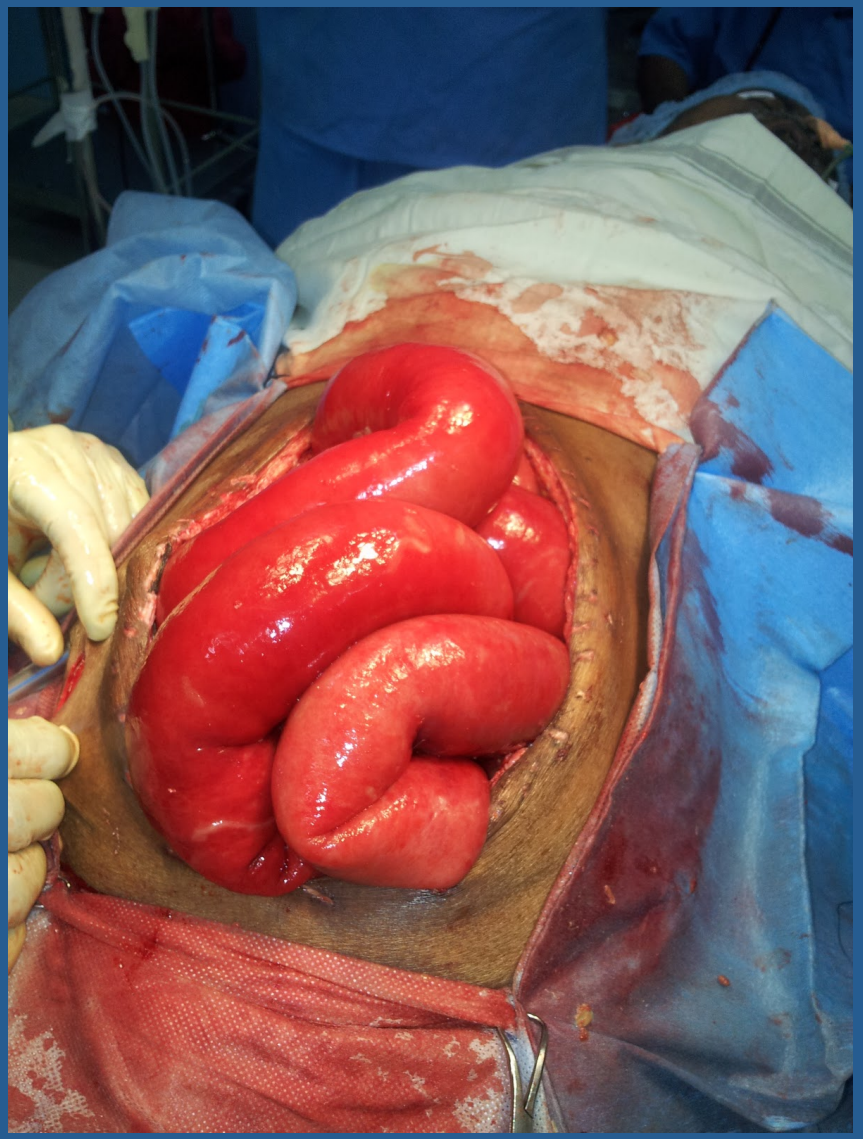




“ Dental squeeze ”

“What goes in… can’t get out! ”

Intestinal gas expansion:
Pain, distention, risk of perforation



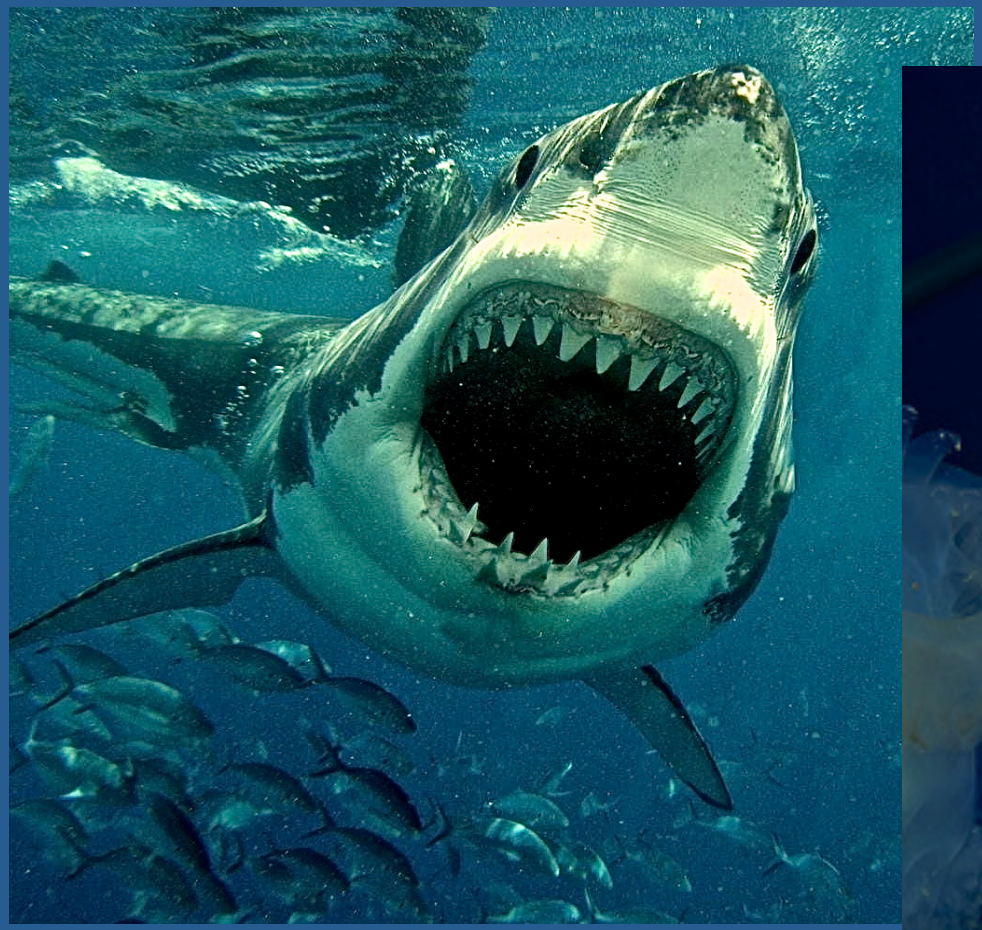
Recommend to avoid, pre-dive:

Severe and Life-threatening Barotrauma:

* The problem of breath-holding on ascent *

The most ominous pattern
of death or severe injury in sport diving

Uncontrolled ascent + breath-holding:
Very Very Dangerous



Panic ascent – could be lethal

“Pulmonary Overpressure Incidents”

Pulmonary barotrauma

Severe and Life-threatening Barotrauma:

* The problem of breath-holding on ascent *

The most ominous pattern
of death or severe injury in sport diving

Often a combination of…
disorientation/hyperventilation/panic…

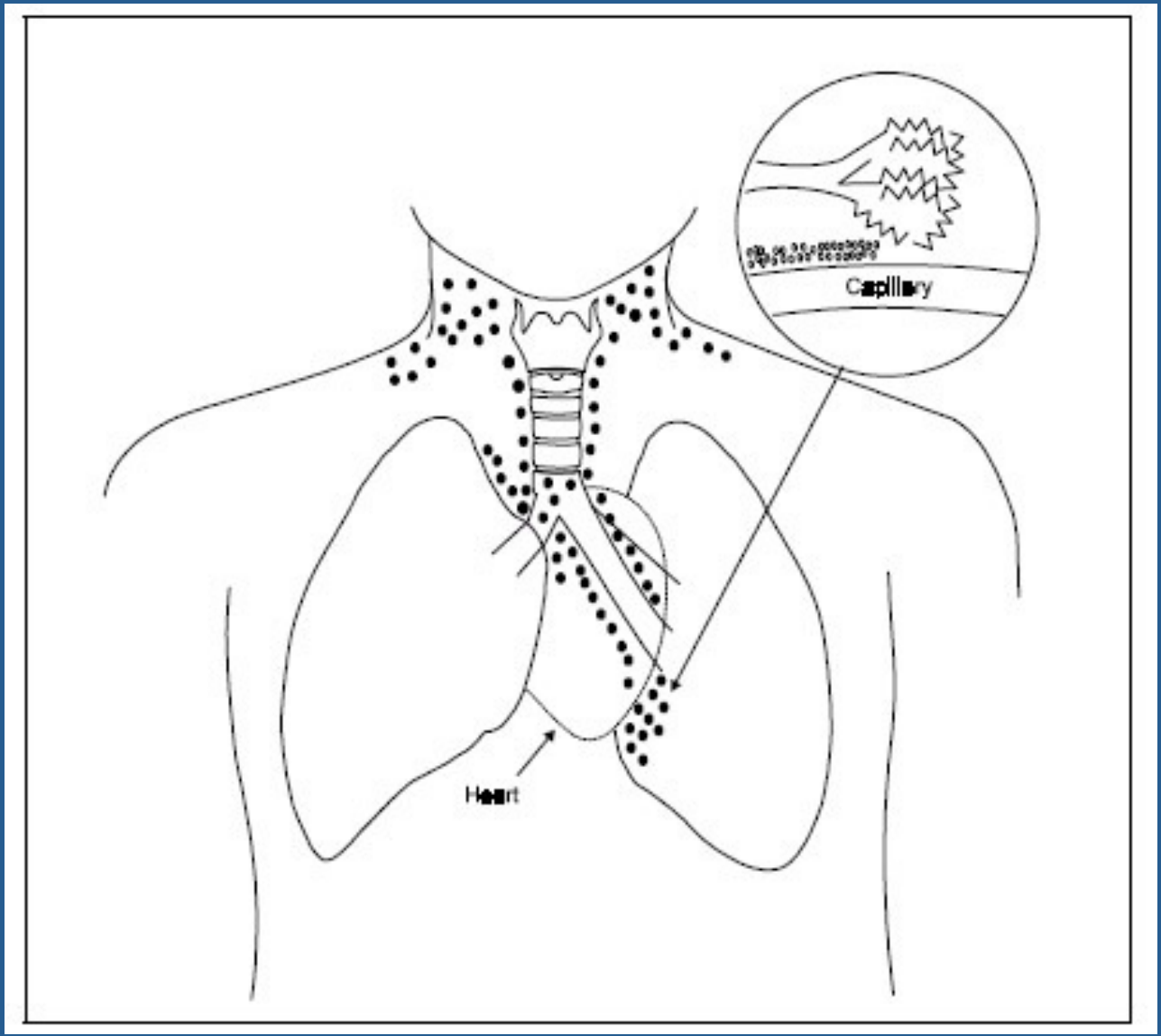
→ leading to aspiration, gasping, more panic

→ bolting for the surface with **CLOSED airway**

→ Acute lung injury, pneumothorax

→ Arterial Gas Embolism and drowning

Rupture of lung tissue: Mediastinal air will track into the neck



Lung tissue (alveolar) rupture:

- Pneumomediastinum

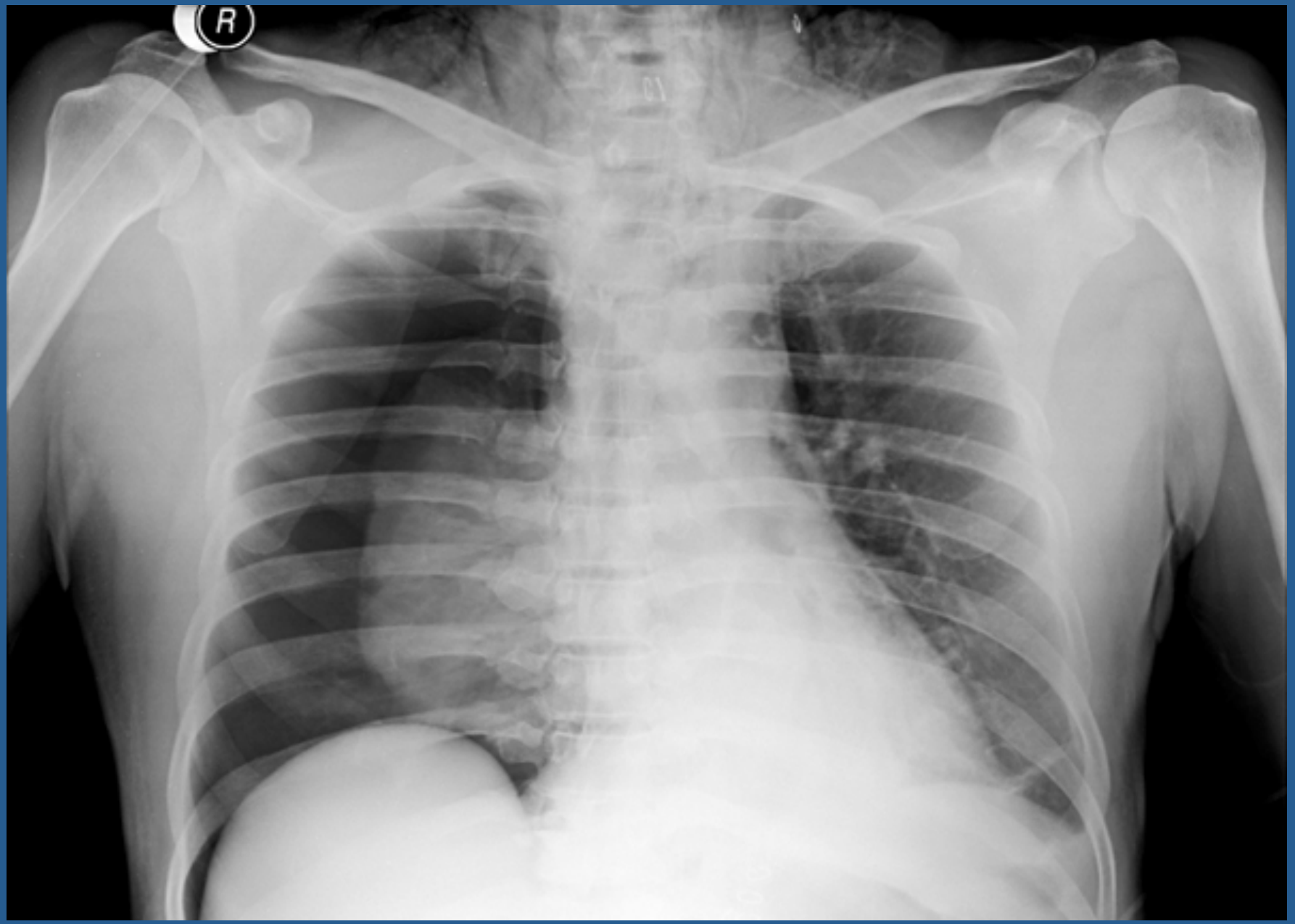
  (air migrating in the neck and chest)
- Pneumothorax ("collapsed lung")
- Pneumopericardium

  (air migrates to the enclosed space surrounding the heart)
- (DREADED) Arterial Gas Embolism

Air migrating in the central chest and neck

Air migrating in the central chest and neck

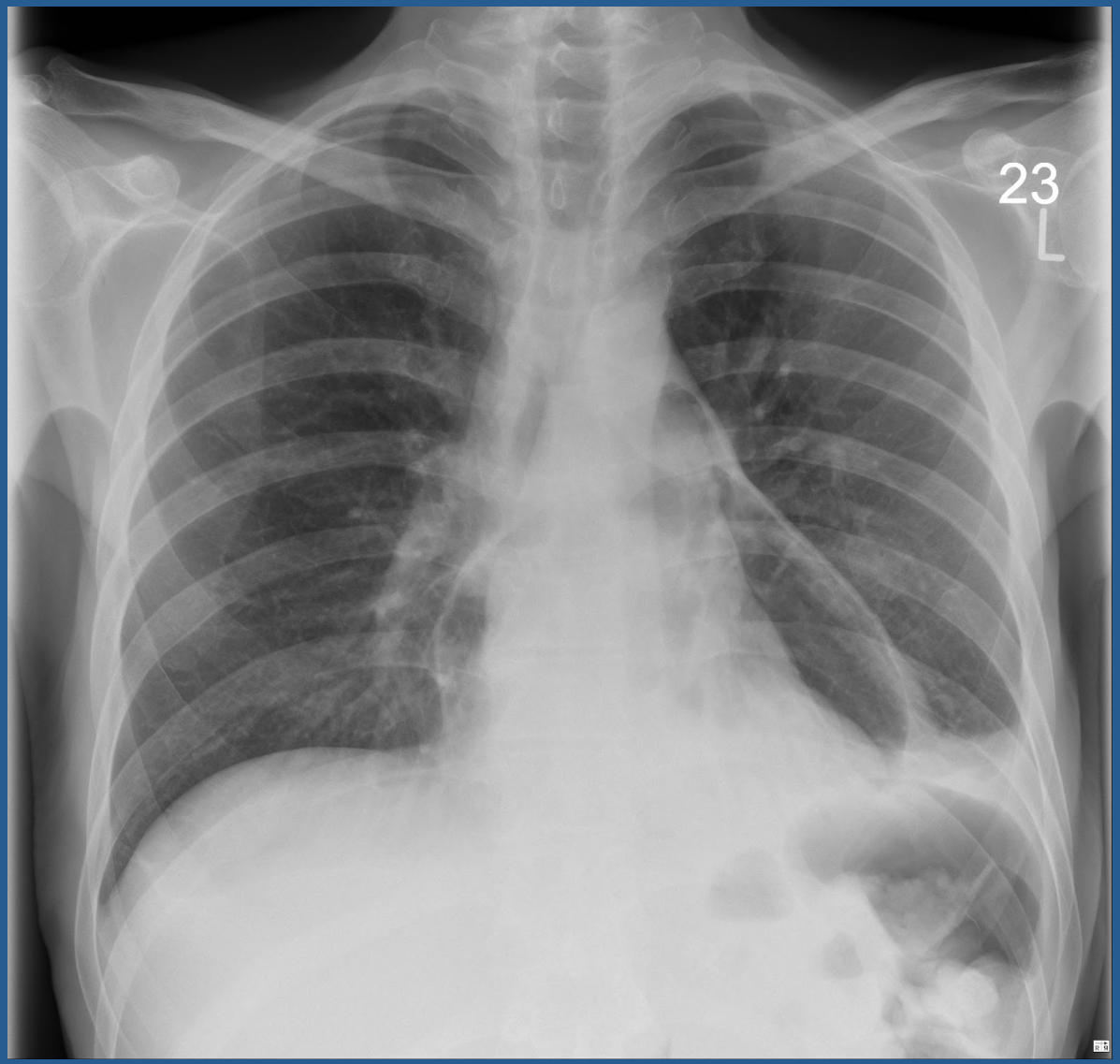
Complete Right Pneumothorax



“Tension” Pneumothorax

Immediate threat to life

Rupture of lung tissue: Mediastinal air can track into the pericardium



Arterial Gas Embolism

Keep in mind:

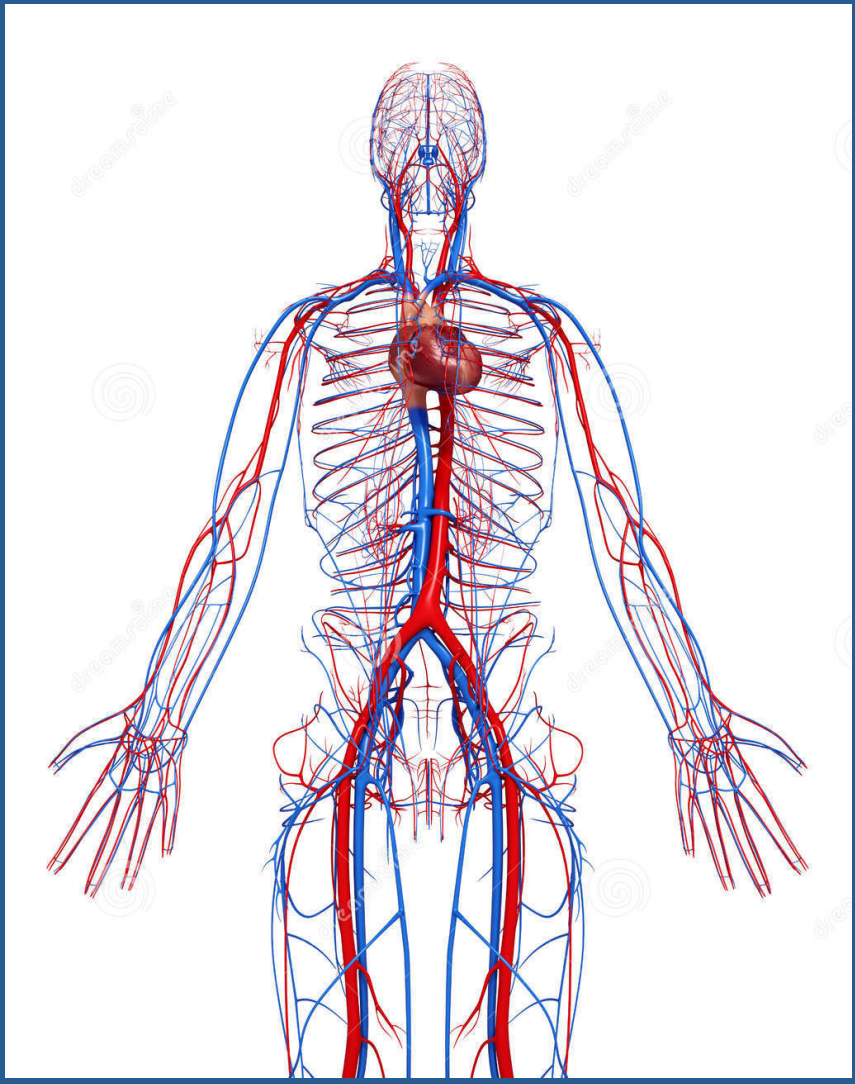
- Breath-holding, during ascent, is the very worse mistake a diver can make.

- This is the No. 1 “take-away point” from this lecture.

Let’s see why:

Q: What is “embolism”?

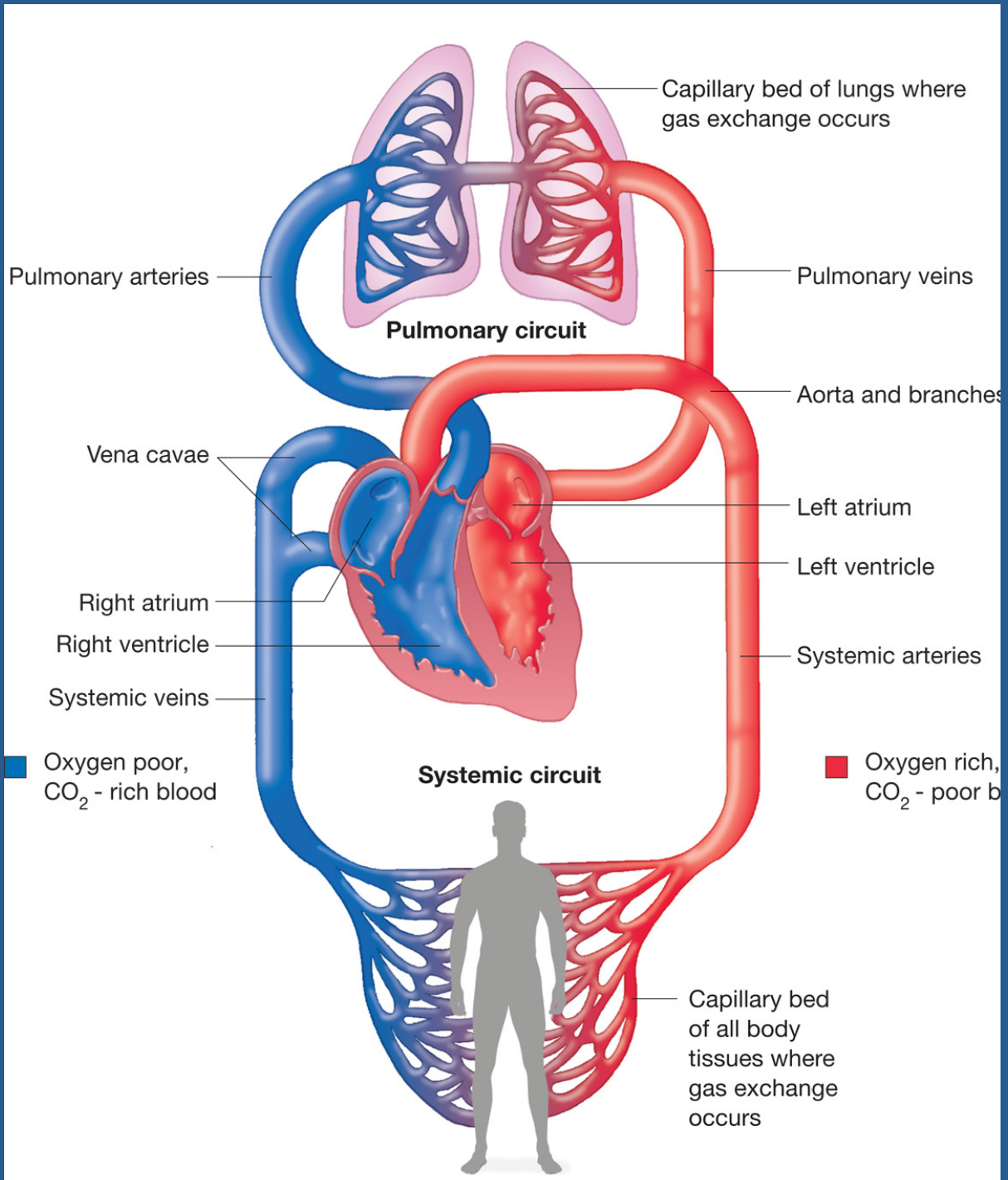
A: Not just a “blood clot” that goes to the lungs

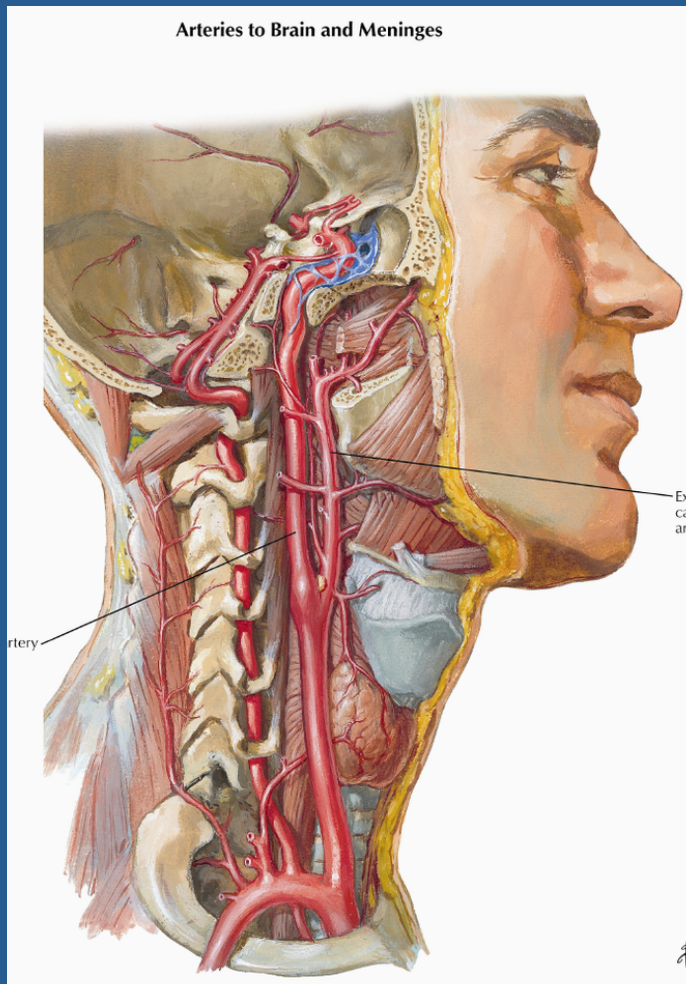


Other things “embolize”:

- ***Infectious debris***
- ***Tumor cells***
- ***Placental tissue***
- ***Fat (long-bone fx)***
- ***Medical devices***
- ***AIR BUBBLES !!!***

Gas bubbles may embolize to the brain



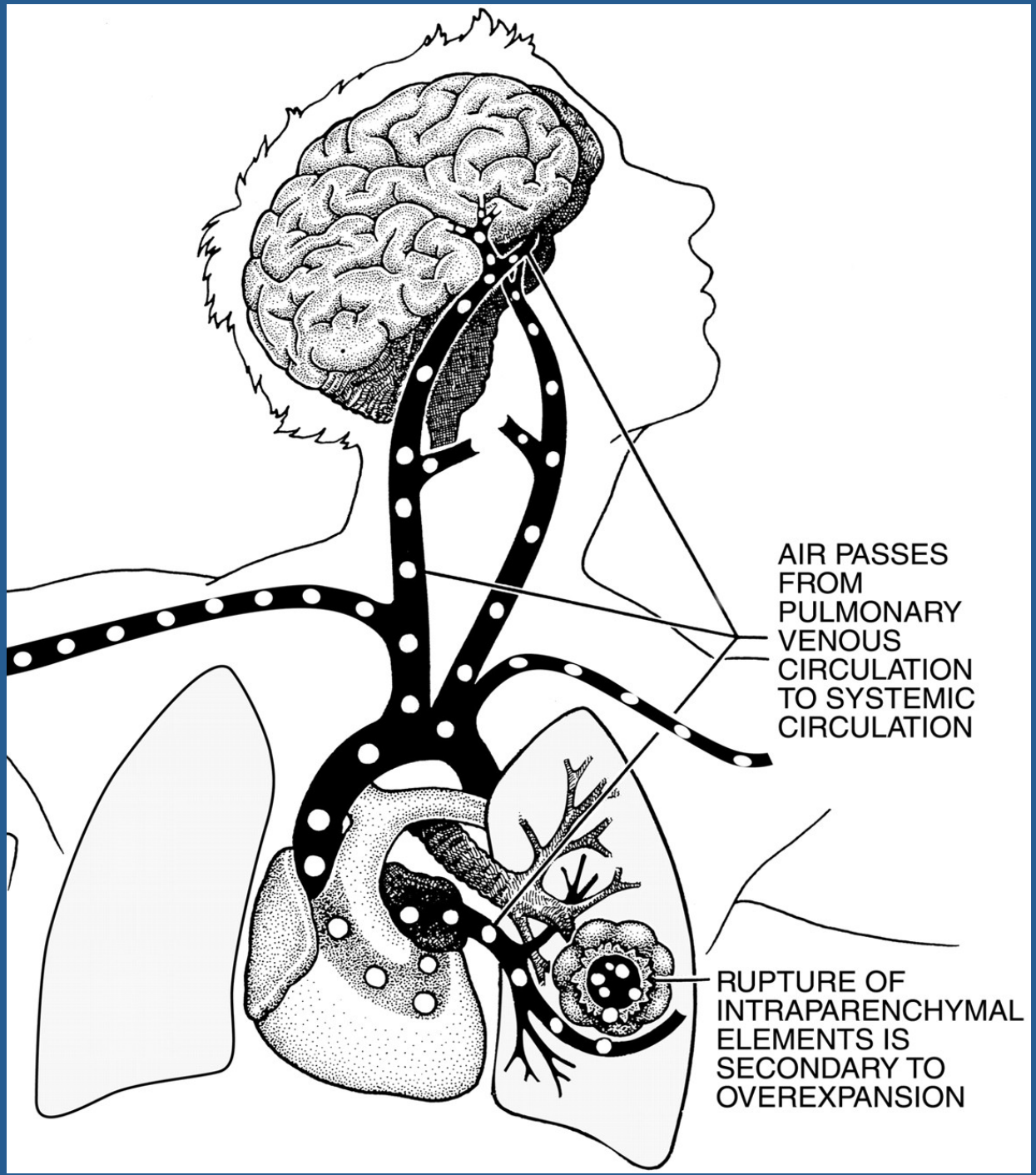


Air bubbles expand → rupture the alveolus:

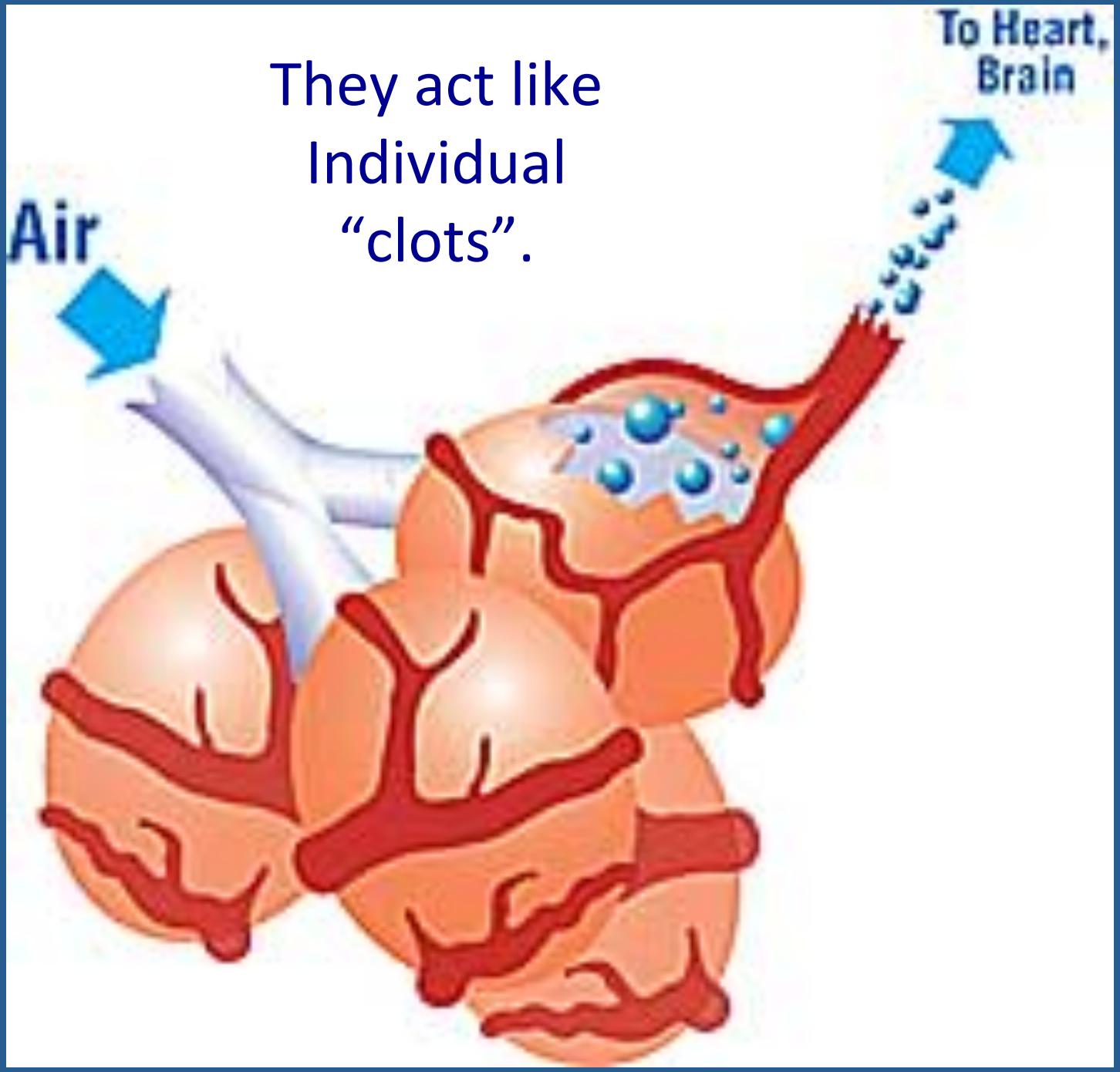
May escape the lungs, into the chest (PTX)

and/or:

May enter the pulmonary veins, and on to the brain and organs


AIR PASSES FROM PULMONARY VENOUS CIRCULATION TO SYSTEMIC CIRCULATION
RUPTURE OF INTRAPARENCHYMAL ELEMENTS IS SECONDARY TO OVEREXPANSION

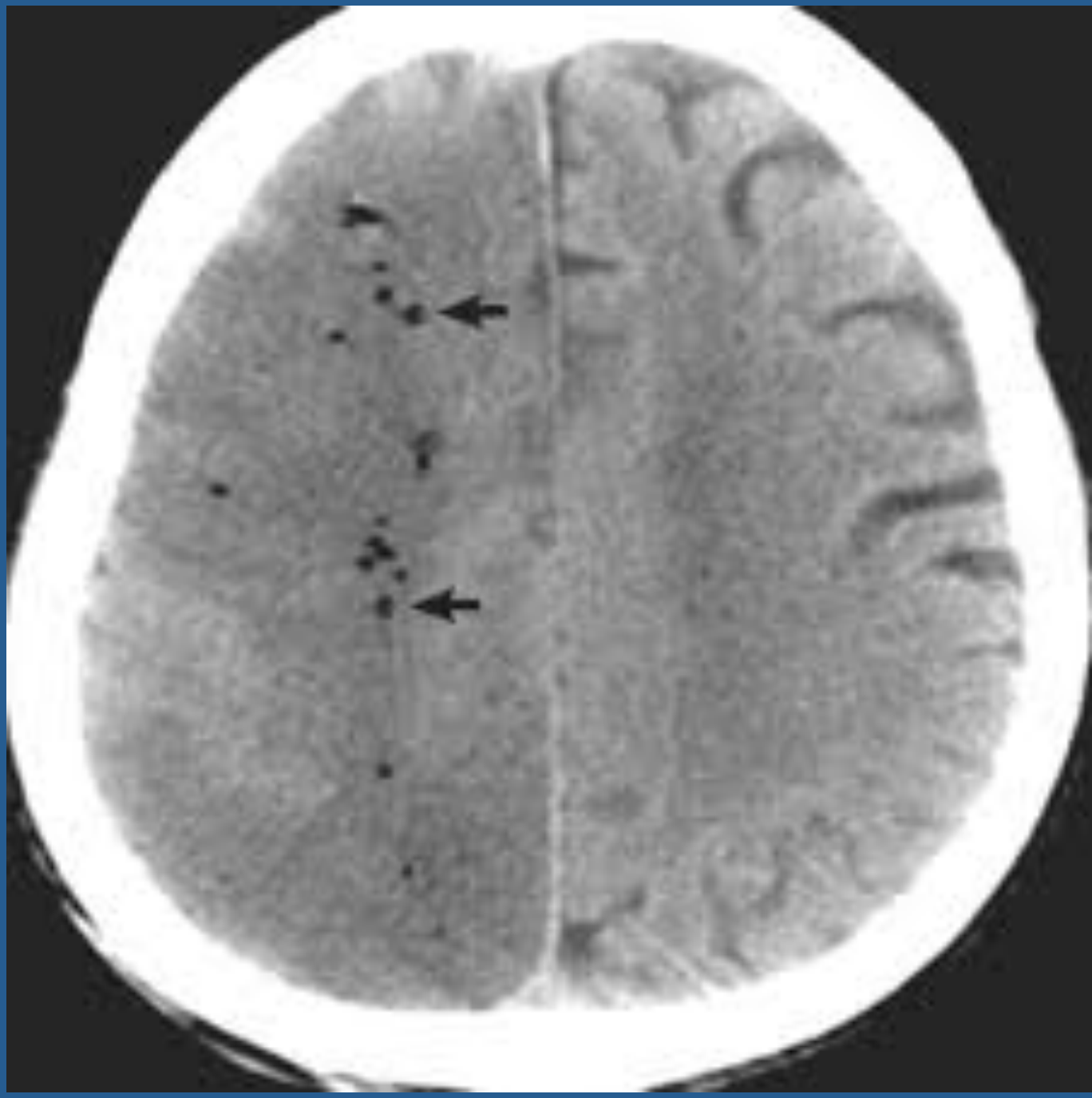
They act like Individual “clots”.



Air bubbles expand with ascent.

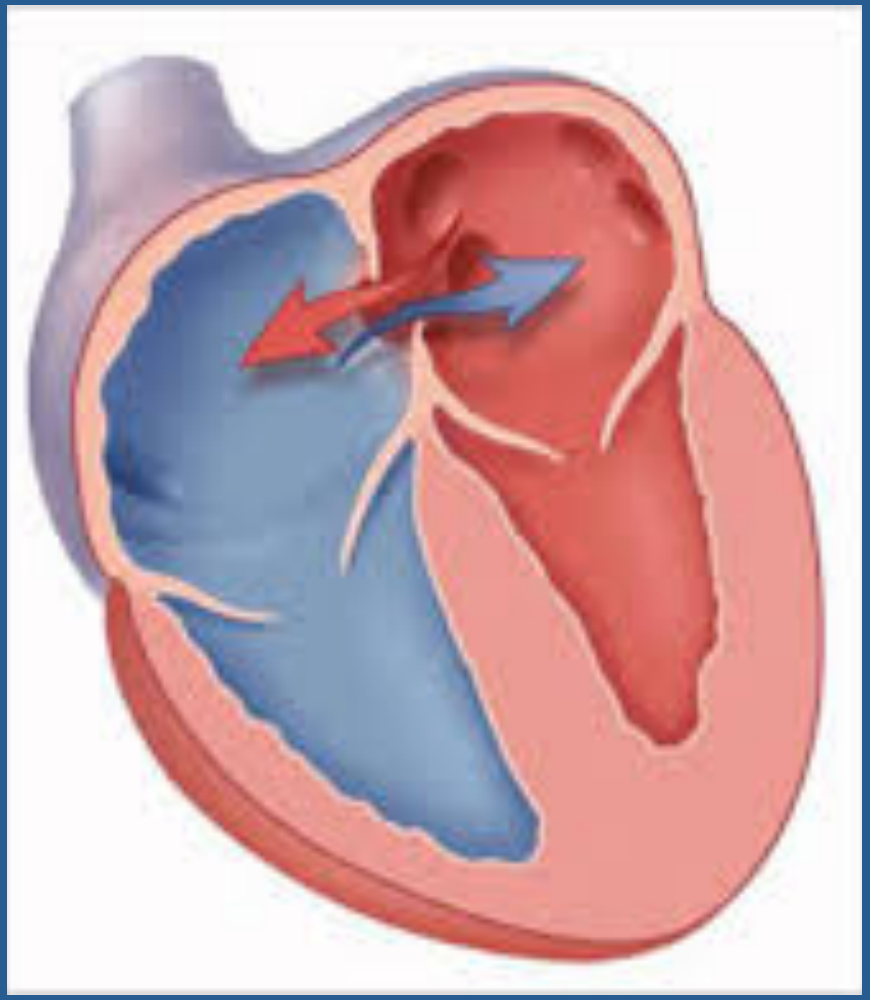
Blood flow obstructed

Cerebral arterial gas emboli



Distribution within the right carotid circulation

Atrial septal defects (25% of pop.)



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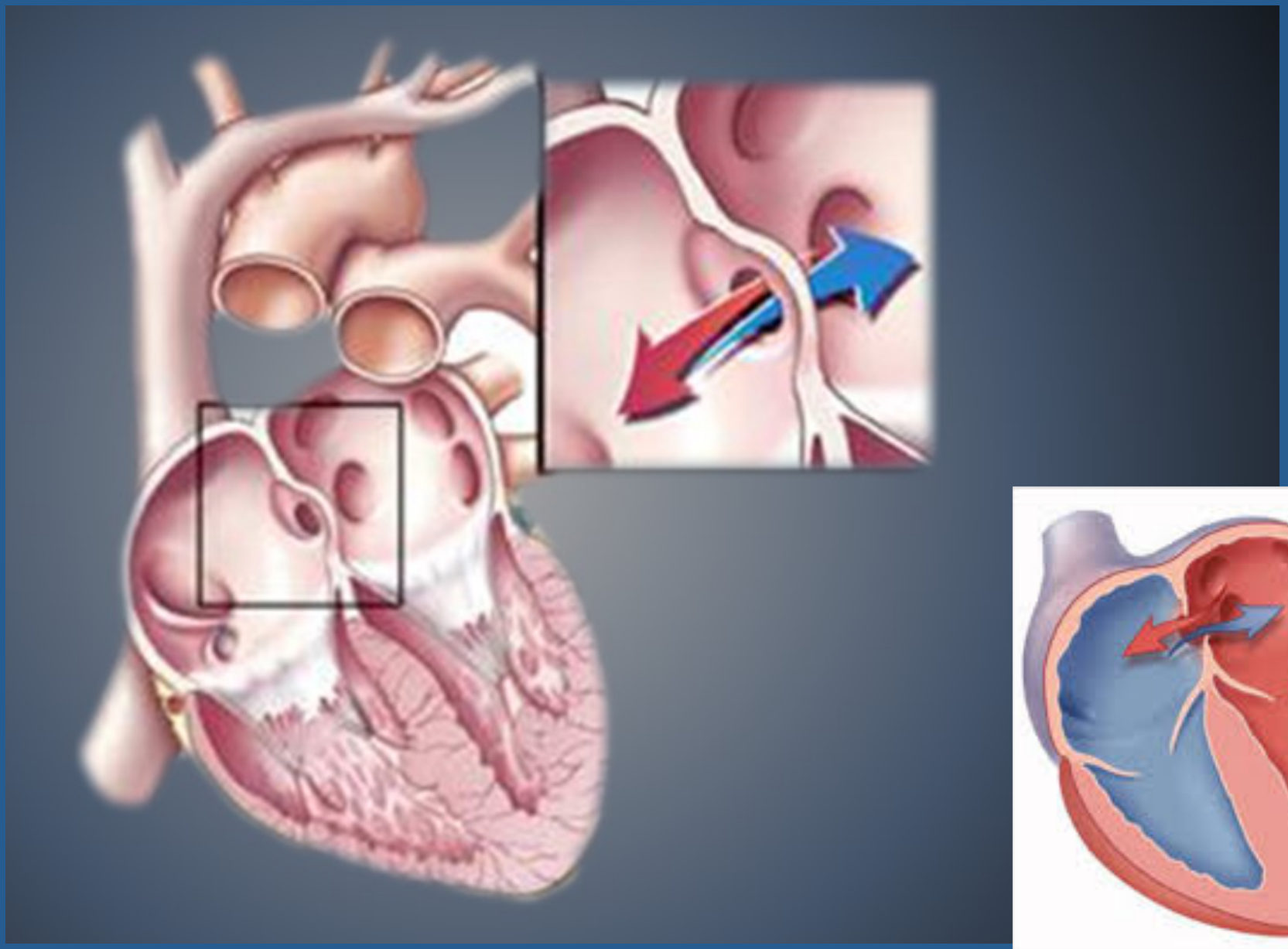
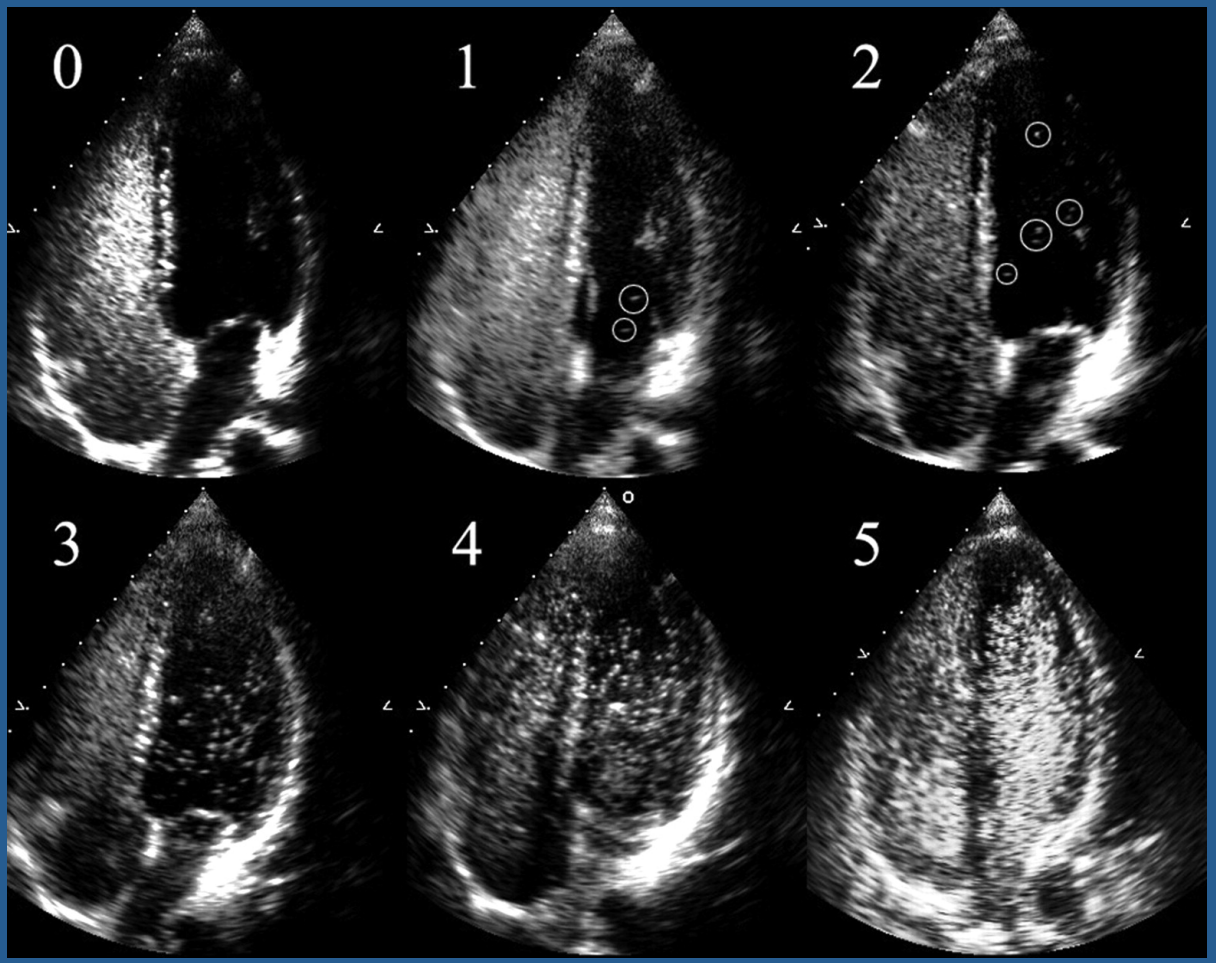
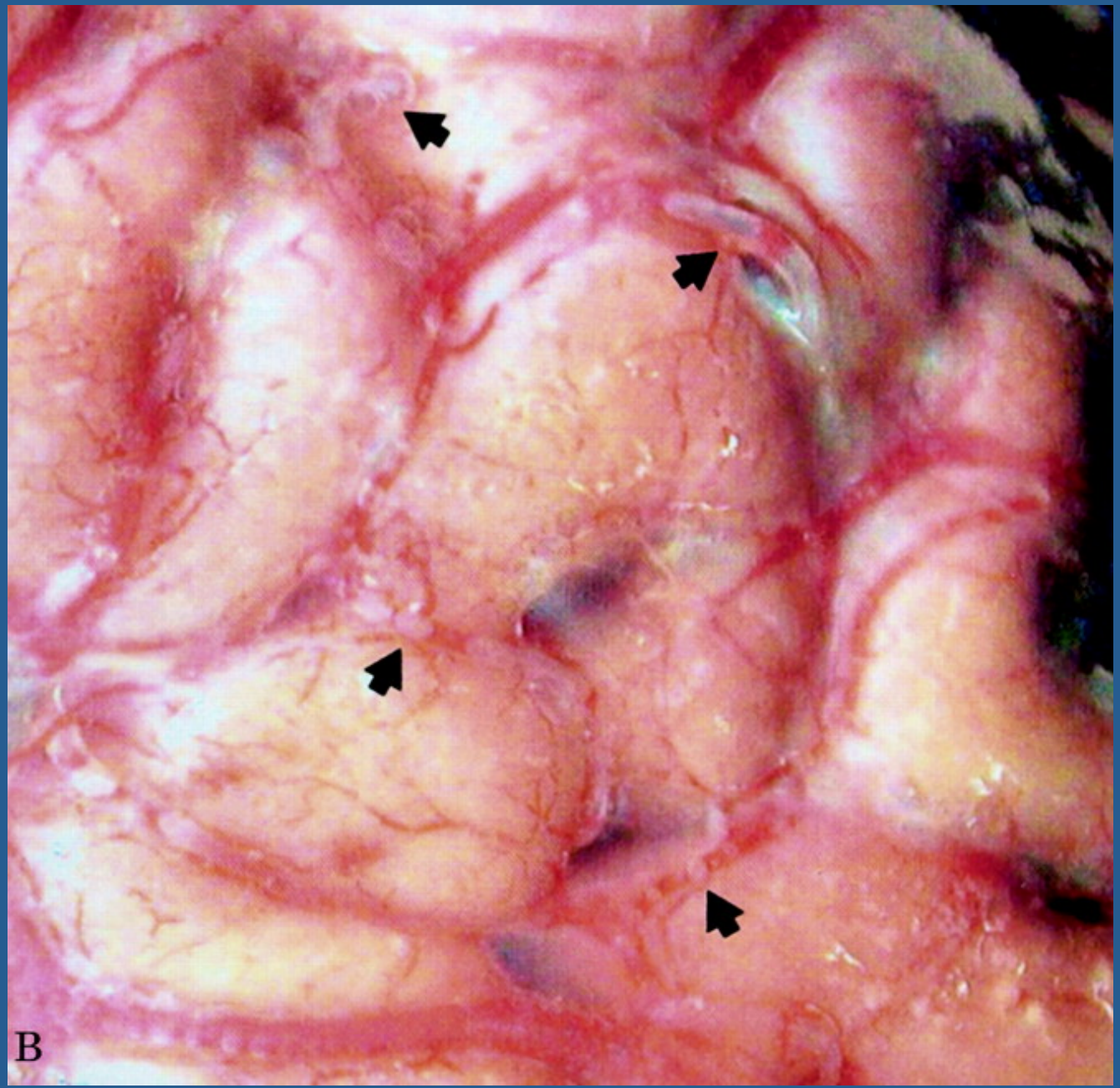


Echocardiogram:
Air bubbles (emboli) traveling between the atria

“PFO” - Patent Foramen Ovale (about 25% of people have it)

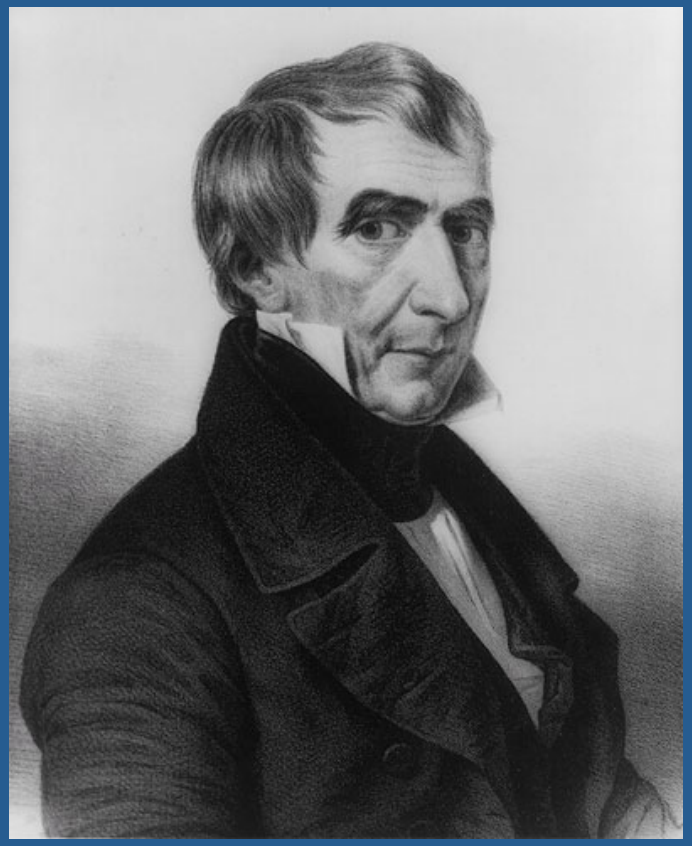


Widespread fatal cerebral air embolism



Decompression Sickness (DCS)

The problem of
*gases **DISSOLVED** in blood*



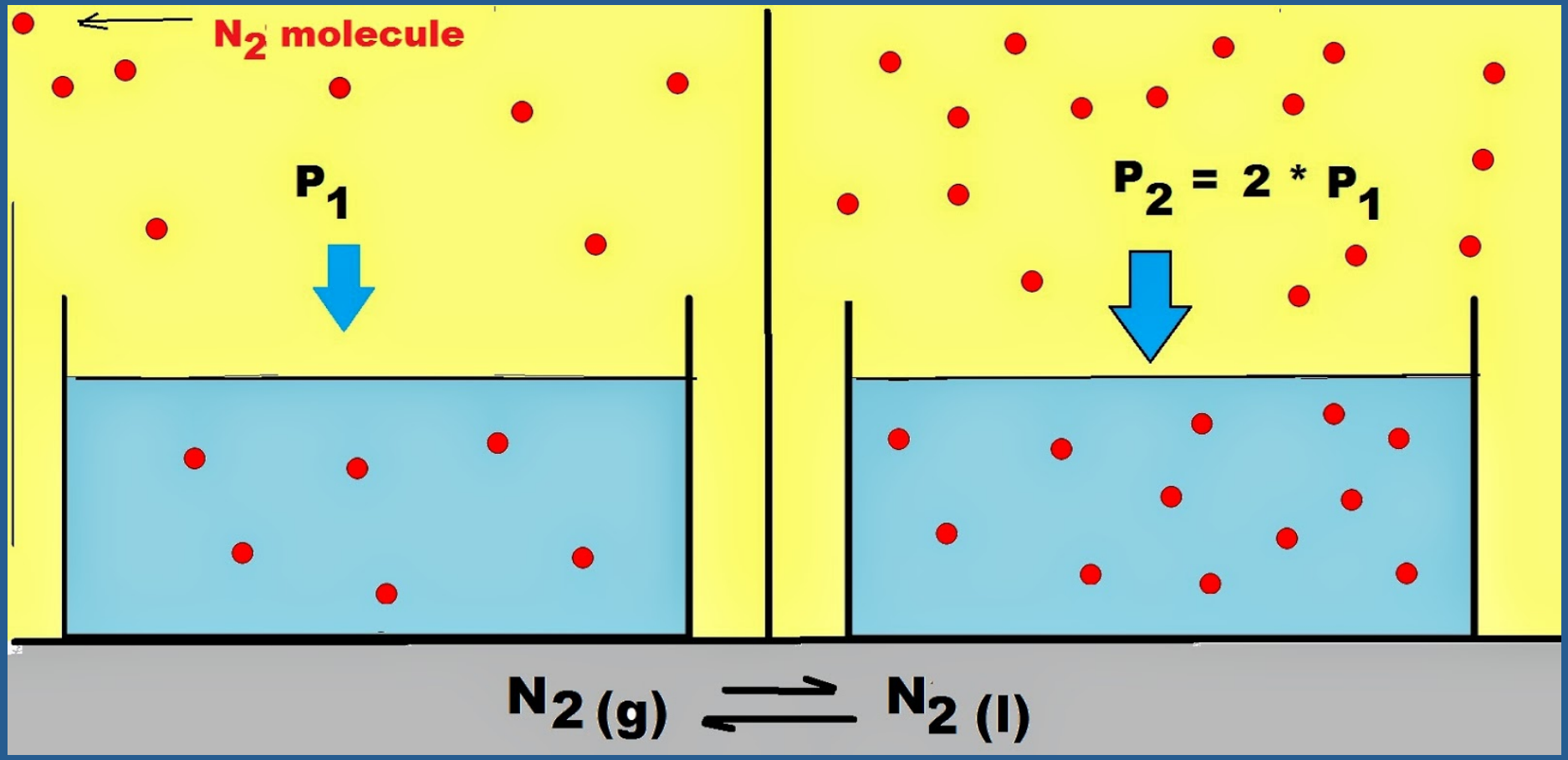
William Henry – 1803


Have a Coke
and a smile.
Coke adds life.

CO_2 pressure released
CO_2 under pressure
CO_2 bubbles out of solution
CO_2 dissolved in solution

Henry's Law in action

Surface = 1 ATM press. 33 ft. down = 2 ATM

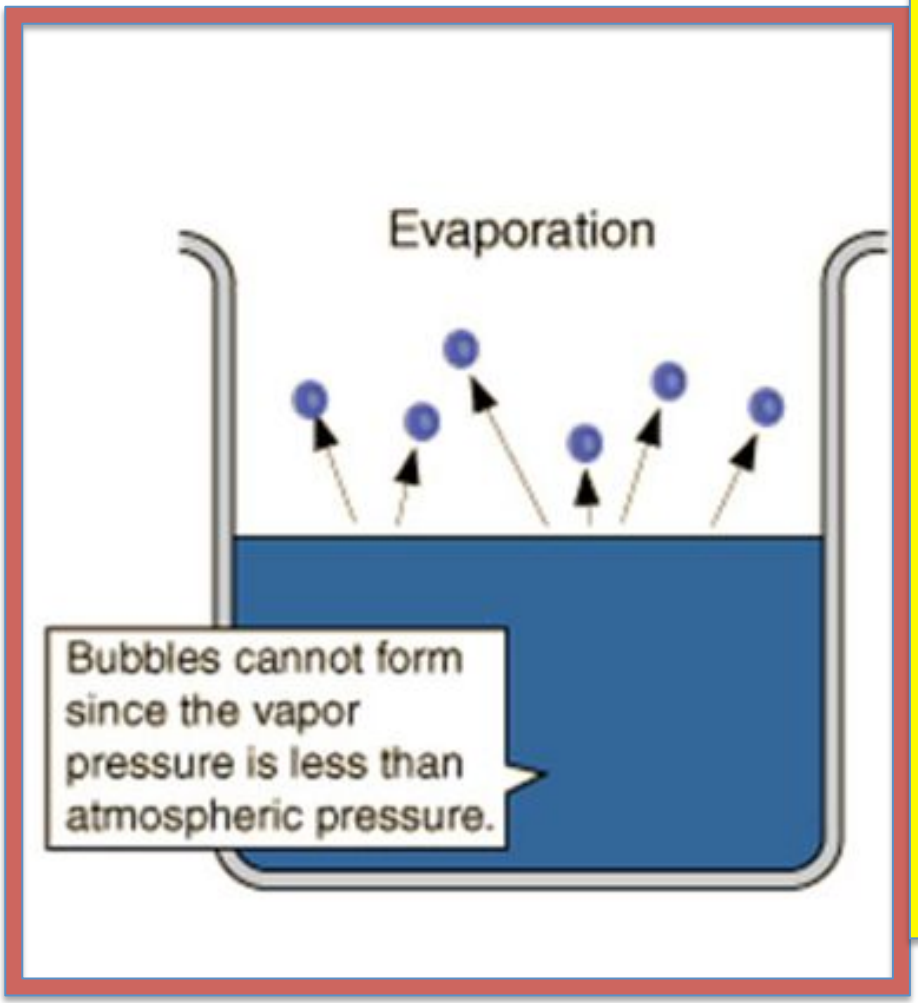


But, what goes in, must somehow get out !

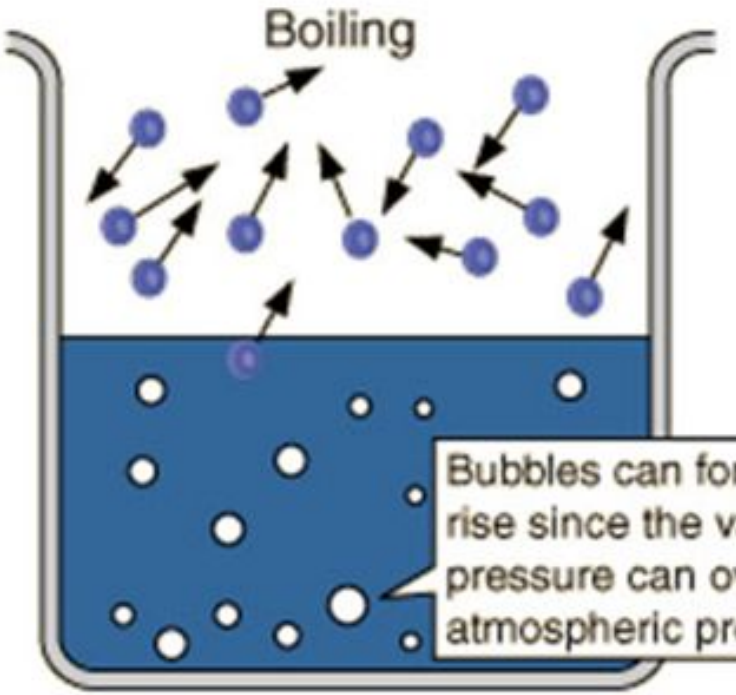
Moving from deeper, to less, depth (less pressure)

At depth: Higher pressure and gas-saturated blood

Going to LOWER pressure too quickly



Gas bubbles form within blood



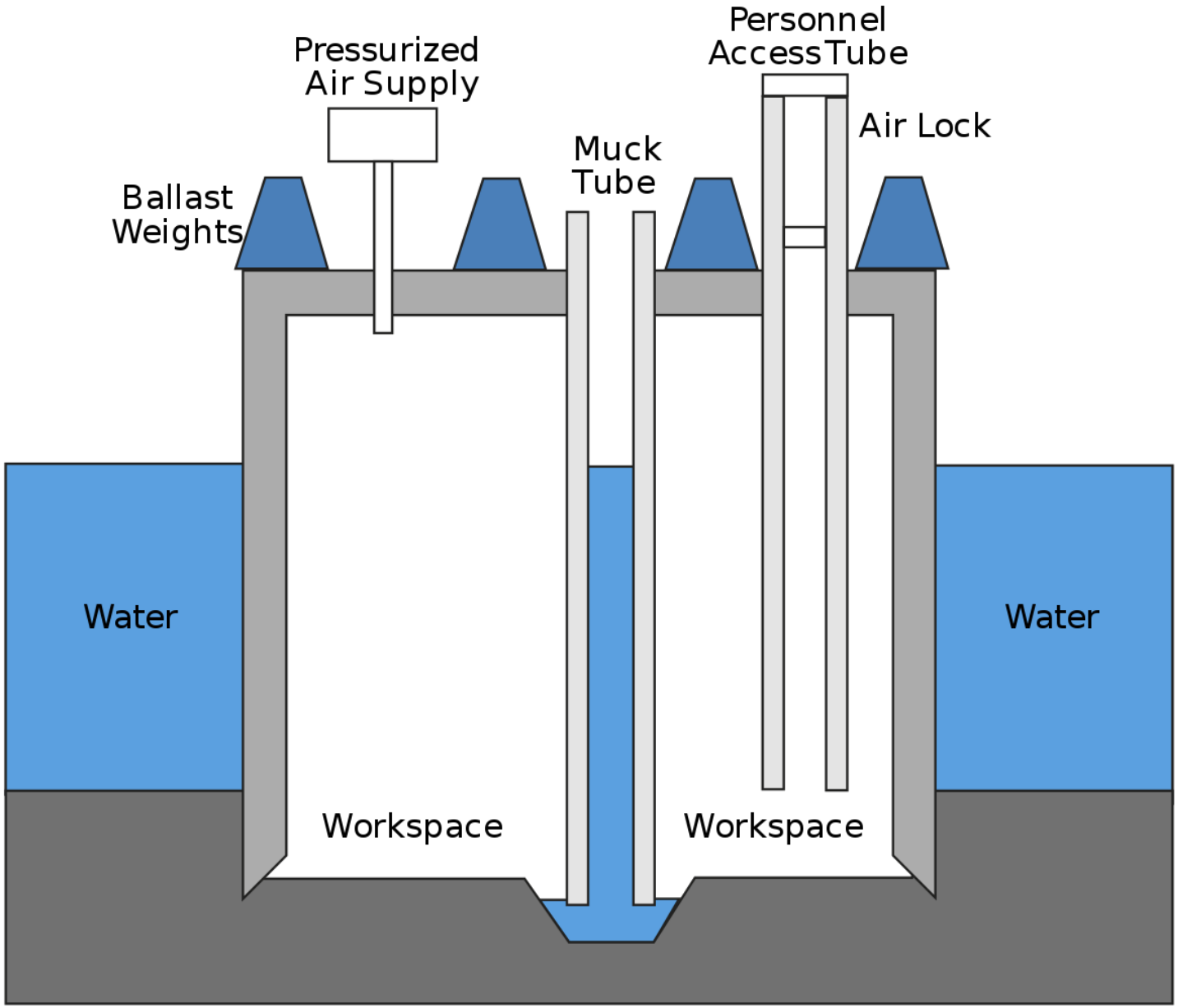
“ The Bends ”

The prototypical DCS

Building the Brooklyn Bridge

Deep down inside, and on the seabed: the Caisson Workers

“Caisson” chamber - diagram



Caisson Workers in the "Elevator"

1.—ENTRANCE TO THE AIR LOCK OF THE CAISSON.

Once "down", they were down for a long time – all day – absorbing gases at 2-5 atmospheres ambient pressure

Remember Henry's Law

What goes in (gases), must come out.

Come up slow, and it comes out as gas **molecules**, and you "breath it away".

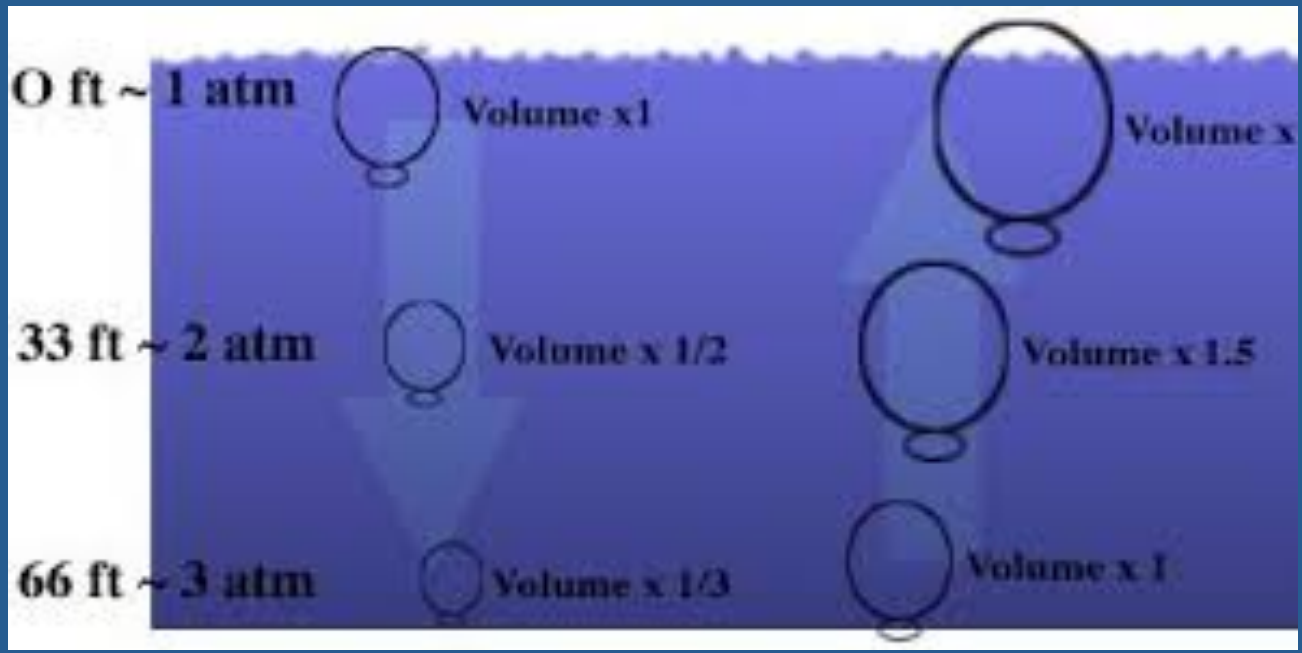
Come up too fast, and it "comes out" by forming ***bubbles*** in your blood.

Decompression Sickness (DCS)

The deeper and the longer the dive, the more gas dissolves in the blood.

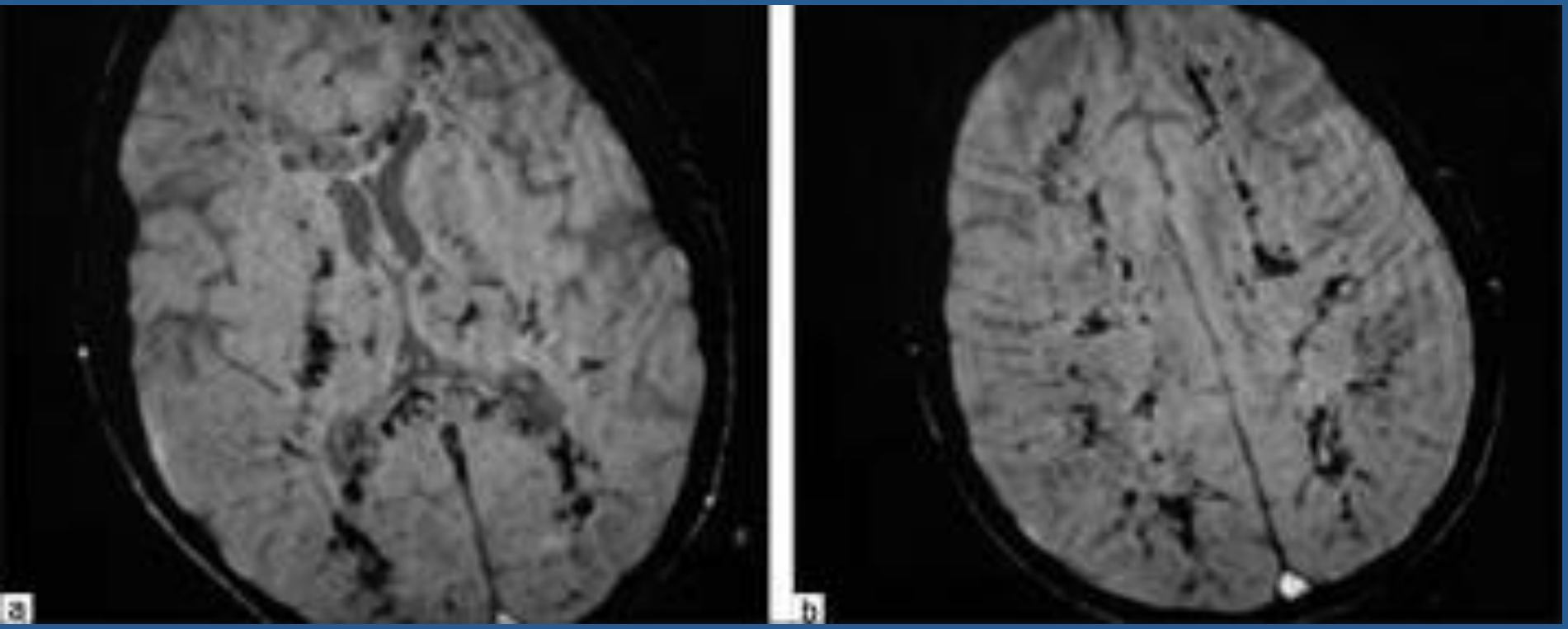
DCS is caused by formation of gas bubbles in the tissues or circulation - as a result of inadequate elimination of inert gas from the blood.

Bubbles expand and travel through the circulation



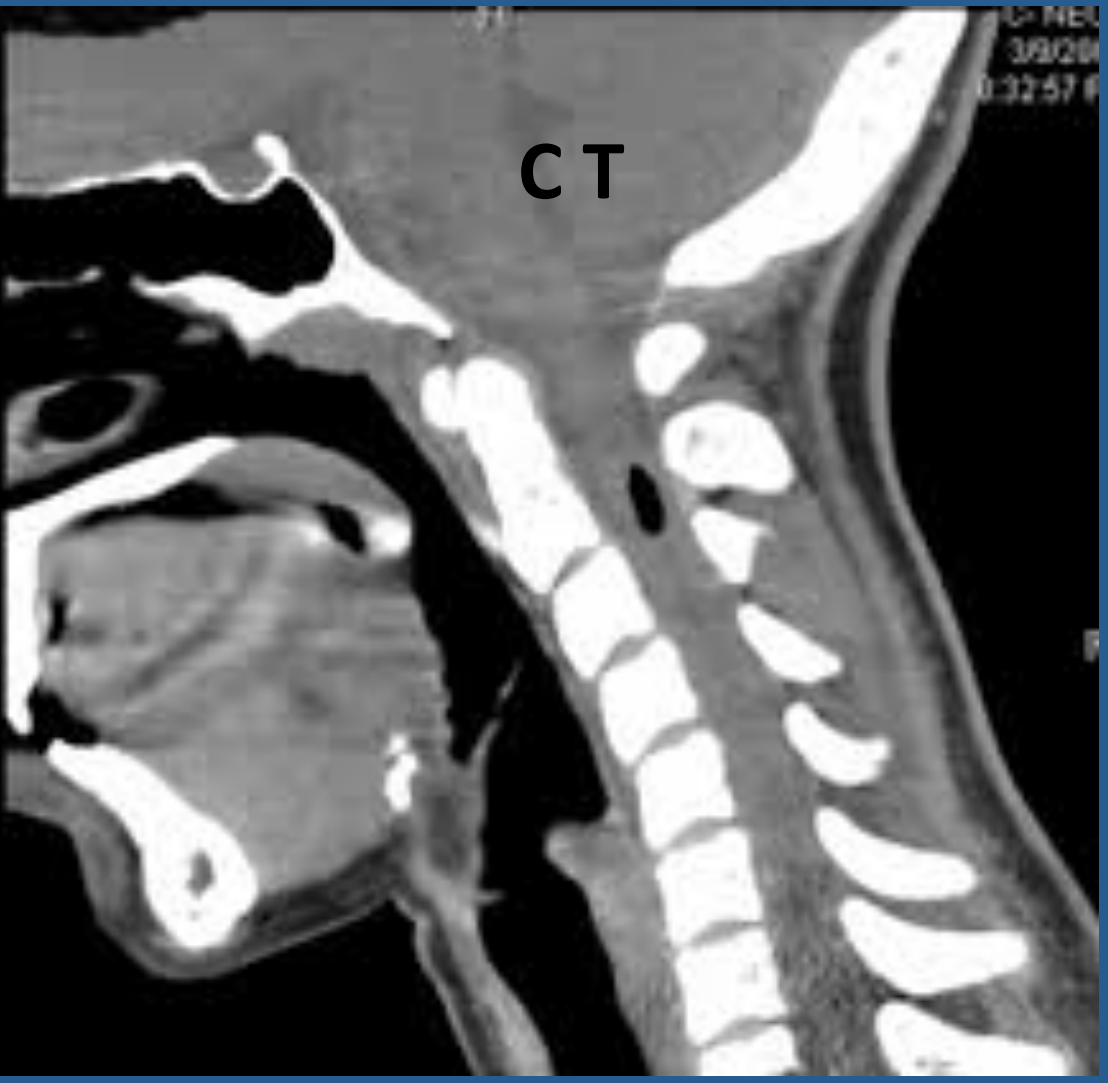
Consequences of DCS

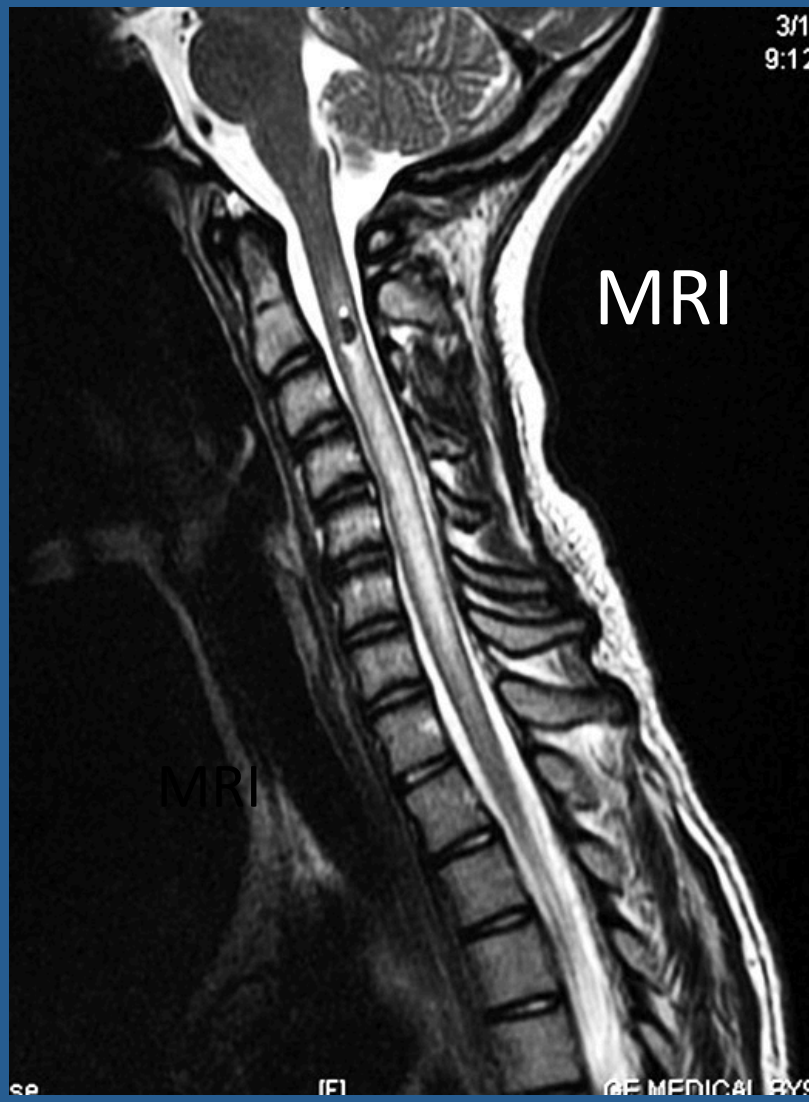
Gas emboli in the brain



Consequences of DCS

Gas emboli in the spinal cord





Consequences of DCS

Gas emboli throughout the skin,
causing widespread cutaneous infarction

Consequences of DCS

Gas emboli in the skin (causing infarcts) and the knee (“The Bends”)

The Bends caused repetitive, crippling joint injury to the early commercial divers.

The name “the bends” was taken from an early 18th-century woman’s manner of walking.

The divers were said to be “bent” when they were severely affected.

Back to Case # 1:
Weird Symptoms at Triage

- What did the Triage Nurse ask ?
- " Did you go diving on your trip? "
- " Did you dive the morning of your flight home? "

" ... you fool ! "

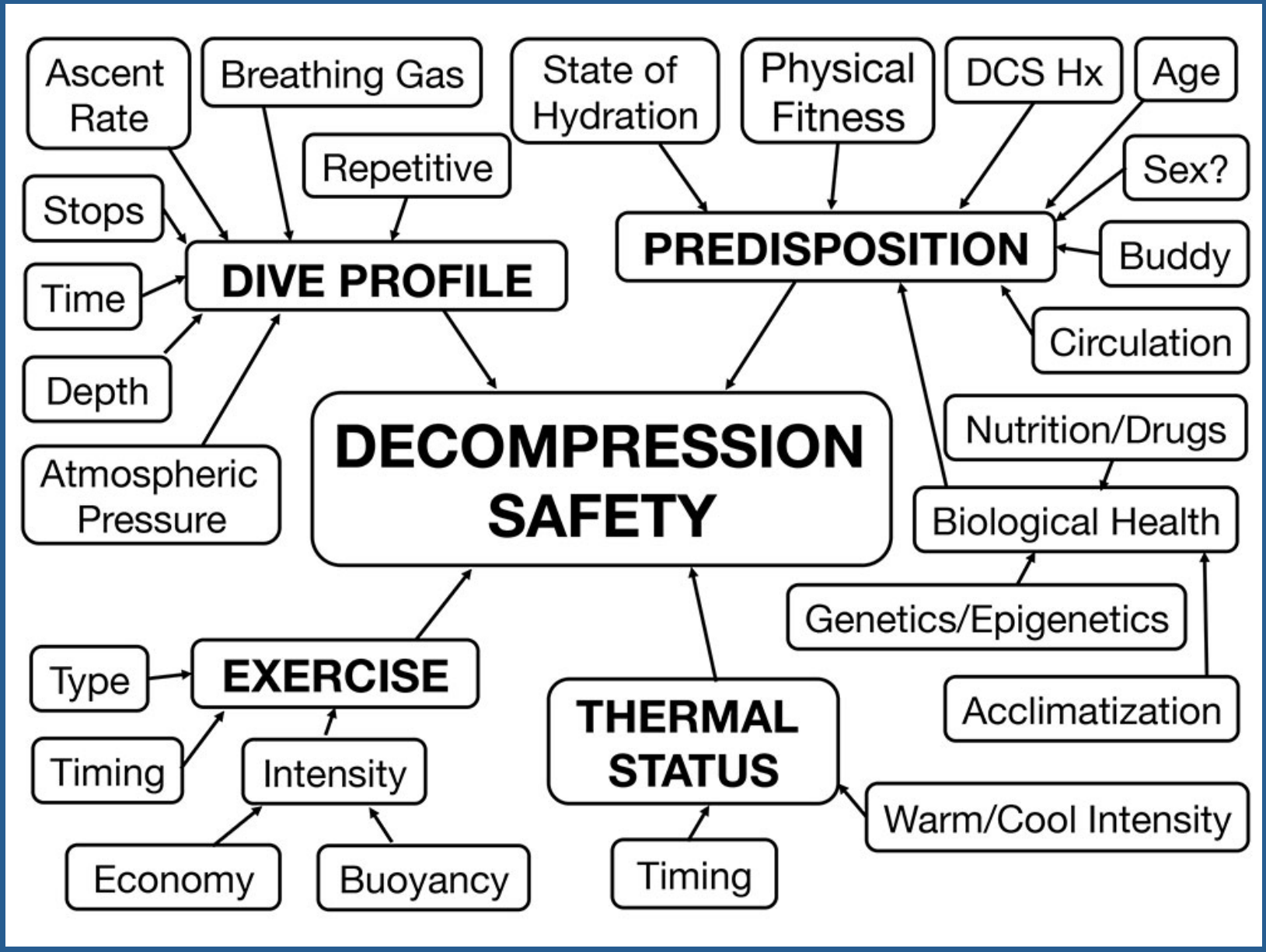
- " How deep and how long did you dive? "
- " You didn't read the book on why not to do this? "
- ***" What OTHER brain-dysfunction symptoms do you have at the moment? "***

Case # 1 *… and the diagnosis is ?*

Decompression sickness with neurological manifestations

- How did this happen? - in Utah ?!?
- What fundamental error did the diver make ?
- What mechanisms of neurological injury could have occurred ?
- What brain/cord systems could be affected ?
- What diagnostic possibilities exit ?
- What can be done, therapeutically, right now ?
- What could be considered, and anticipated, starting right now ?
- What is the prognosis ?

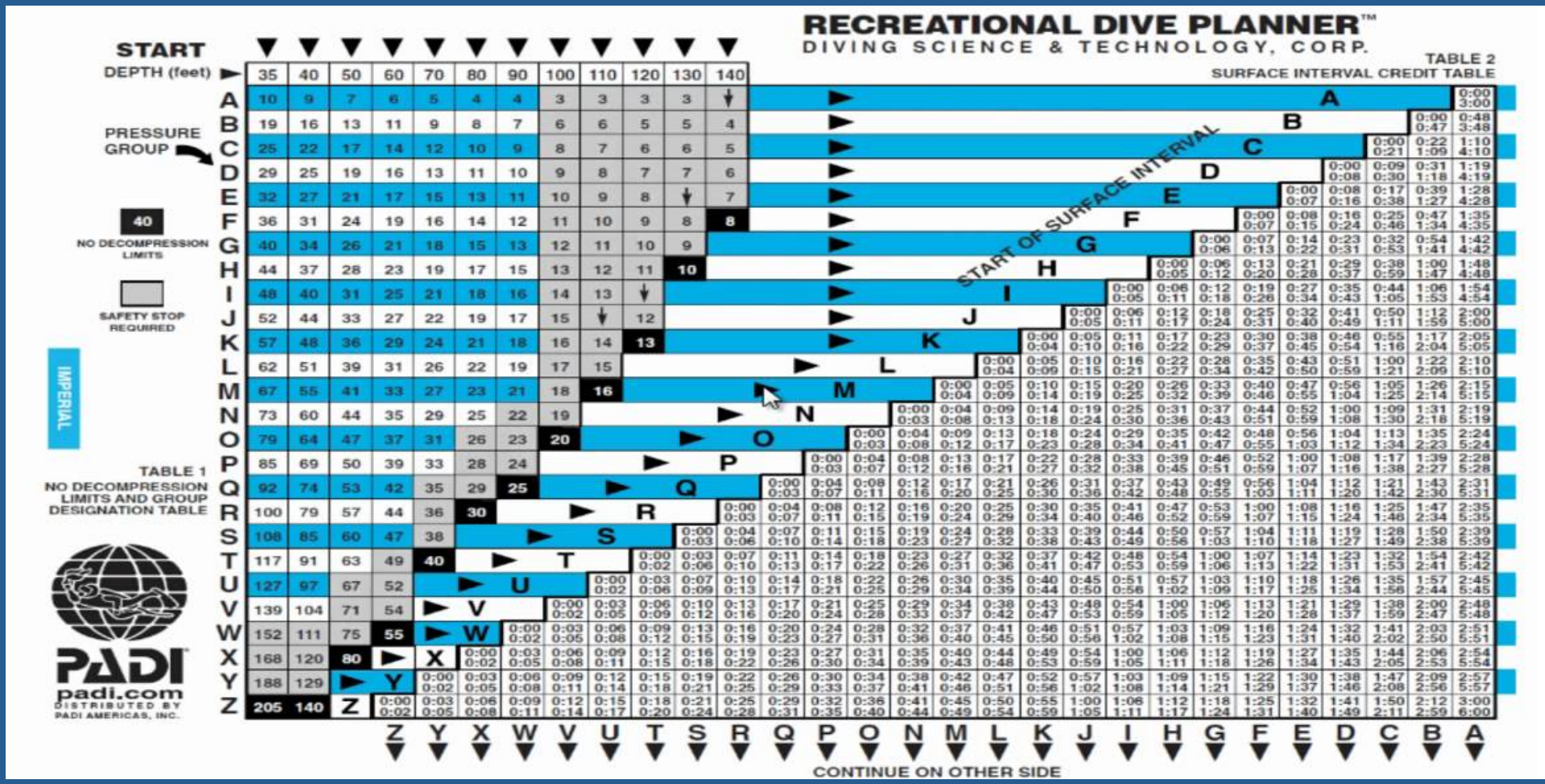
Is just a simple “hunch” good enough ?

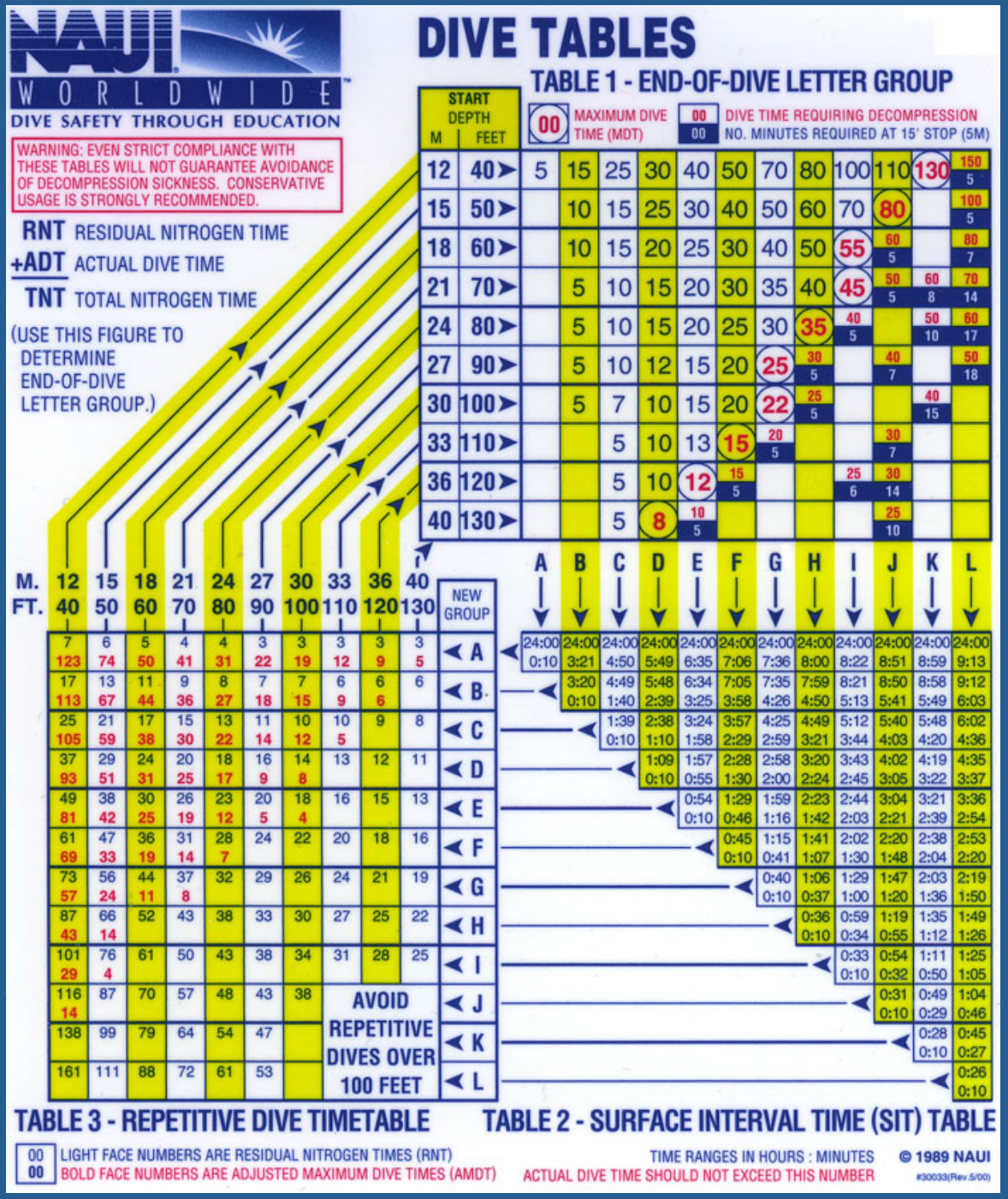


Avoiding DCS

- Most important: PLAN YOUR DIVE.
- Know your depths and time profiles.
- Don’t guess with the decompression risks.
- DO NOT USE the old “Navy Dive Tables” (WW2)
- Understand everything about the causes, effects, symptoms, of DCI

Put this on your "Quarterback's wrist band" ?

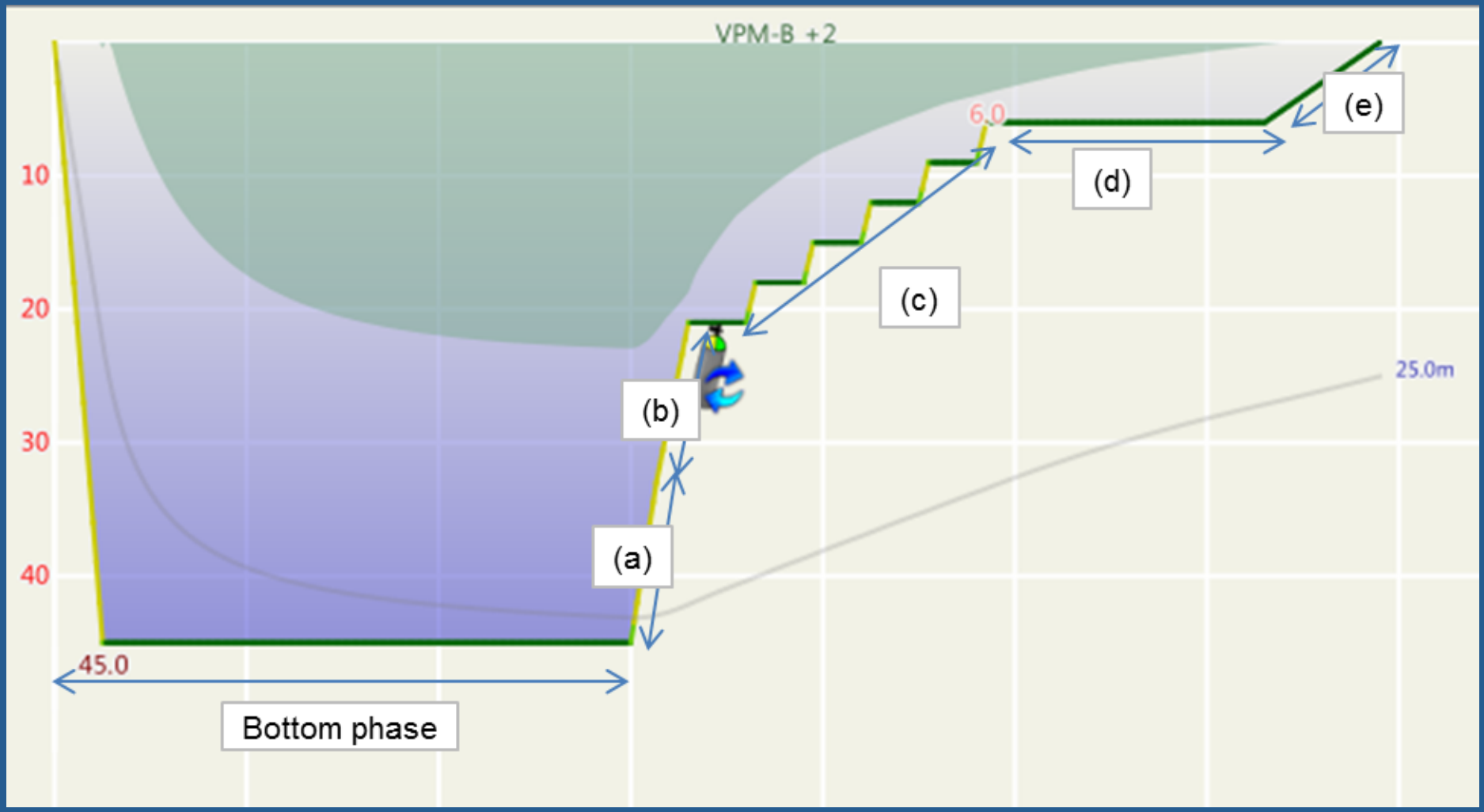


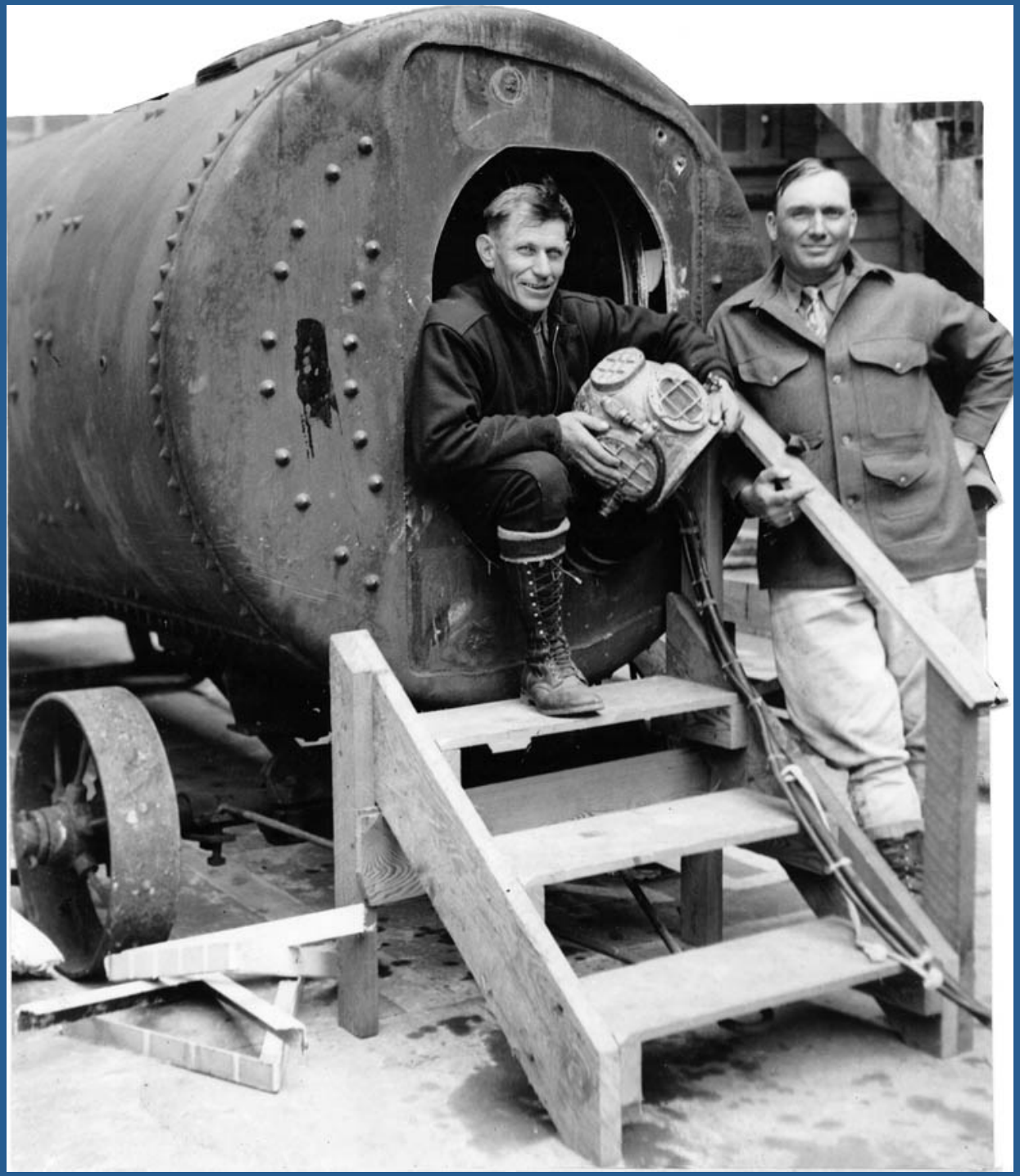


Is it better if it's in color ?

Lots of new technologies available

Example of a decompression profile



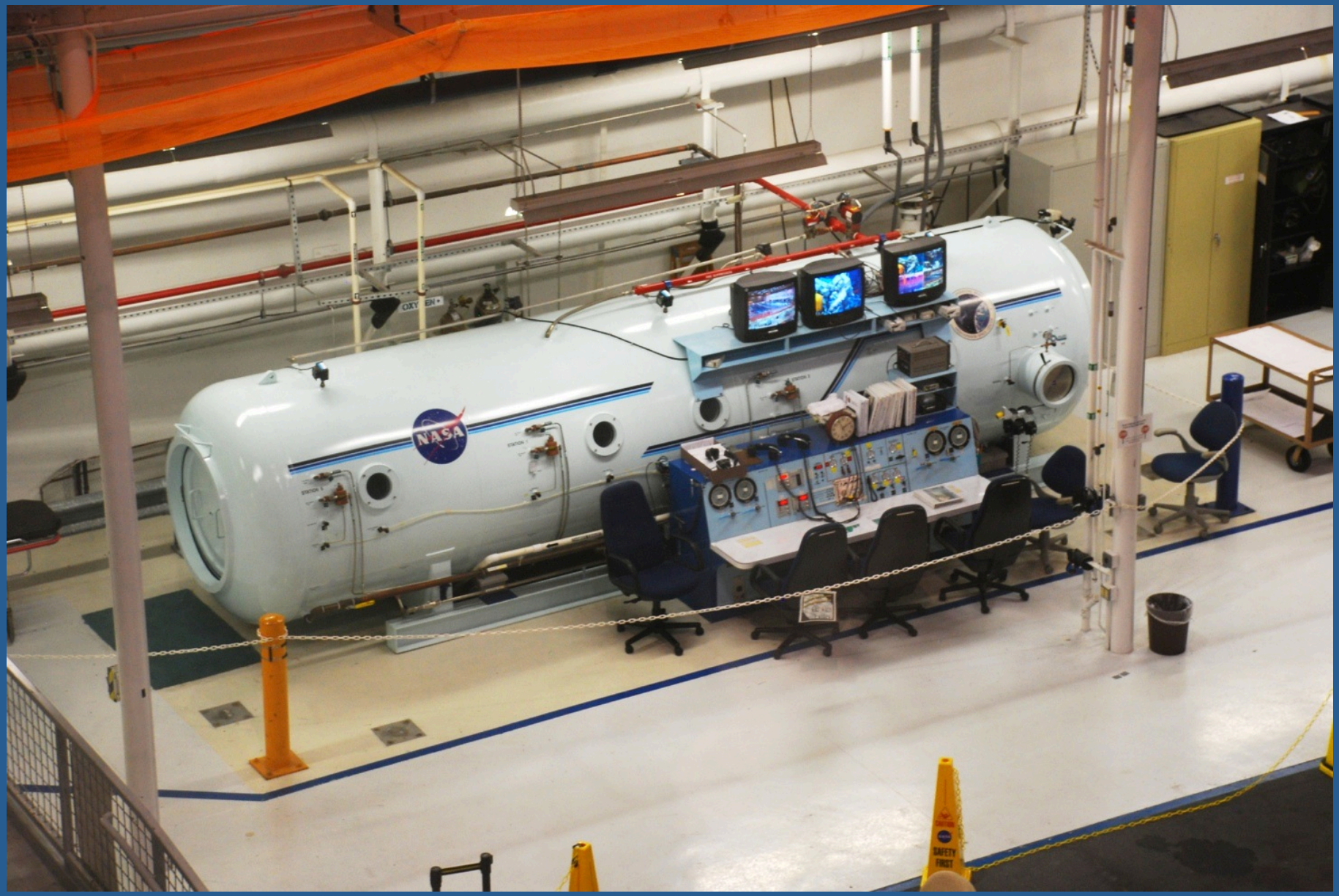


Hard-hat divers

Early Recompression chamber

Portable Recompression Chamber

Recompression Chamber at NASA



Prevention of AGE and Pulmonary Over-pressure Incidents

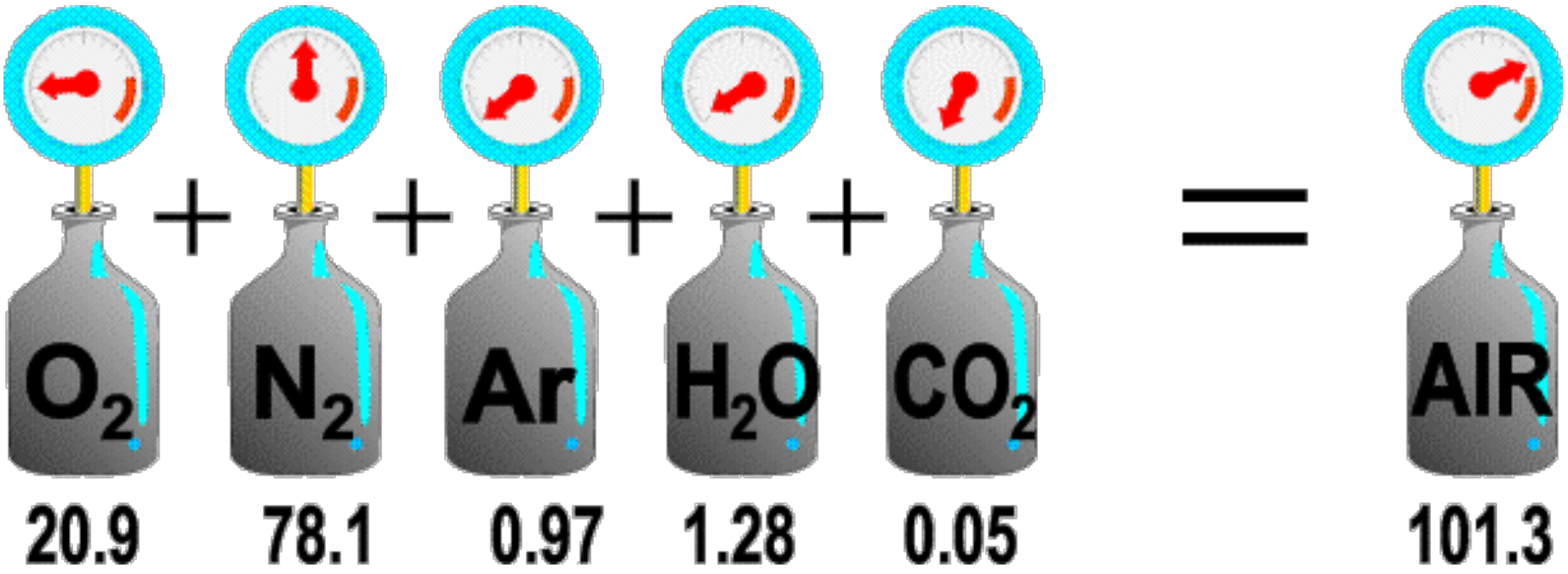
Rapture of the Deep: Nitrogen Narcosis

"Rapture of the Deep" - Nitrogen Narcosis

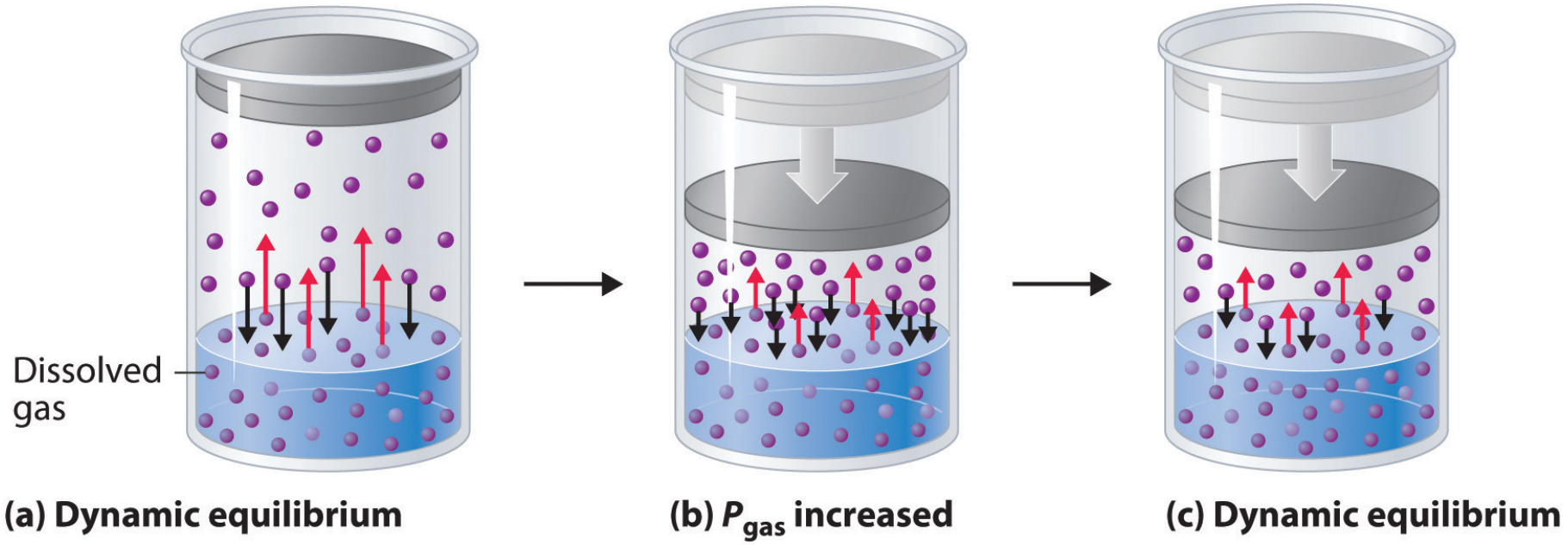

TOONVECTORS.COM

Dalton's Law of Partial Pressures:

The sum of the pressures exerted by all the different gases must add up to the total pressure in the environment.



Nitrogen Narcosis
Henry's Law: The Law of Dissolved Gases



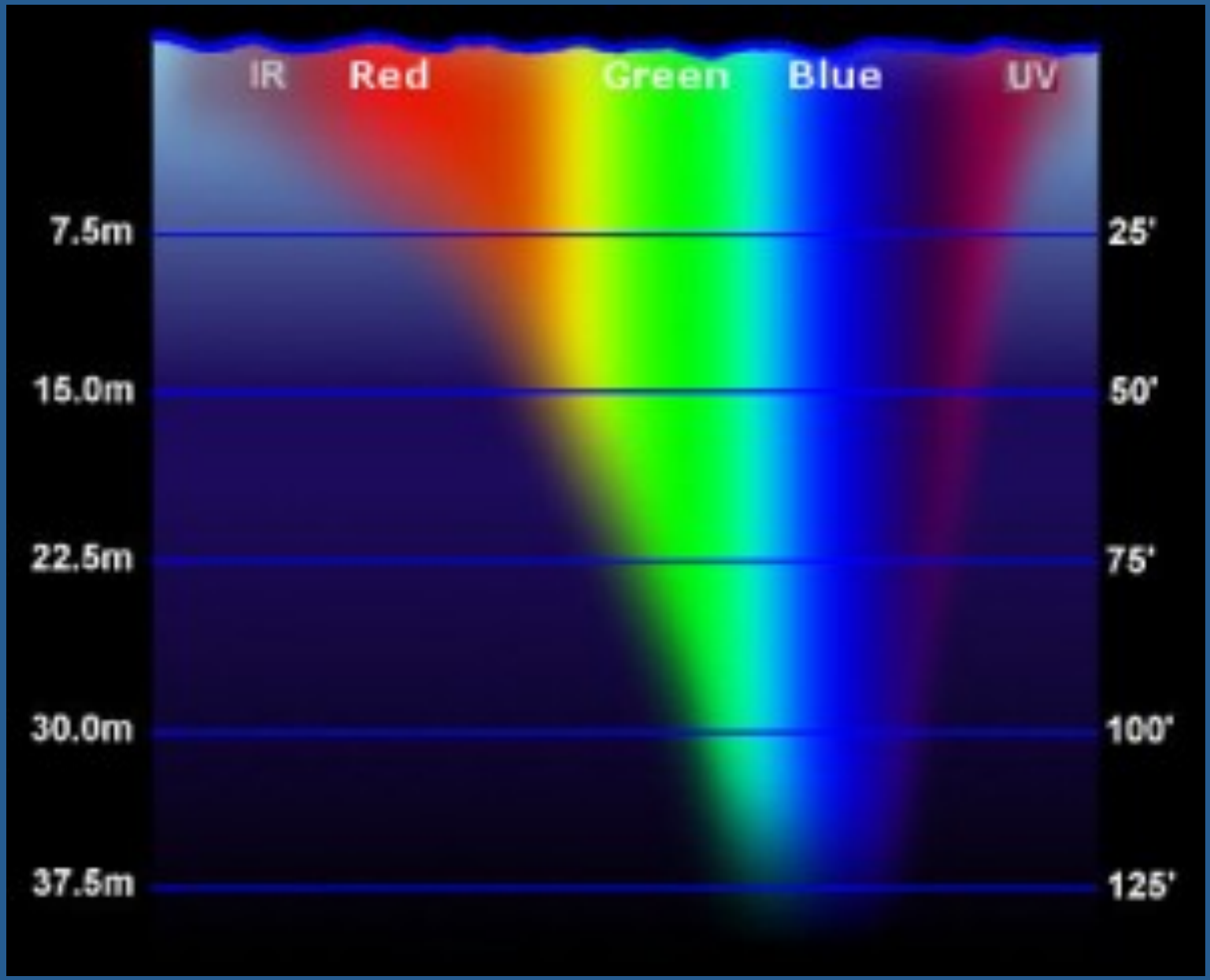
Inert gases, in increased concentrations, act as ***anesthetics*** to the nervous system.

Increased pressure: ALL GASES dissolve further: More molecules, more mass.

Case # 2

Fourscore-and-ten years ago…
in an Ocean far far away… (Hawai’i)

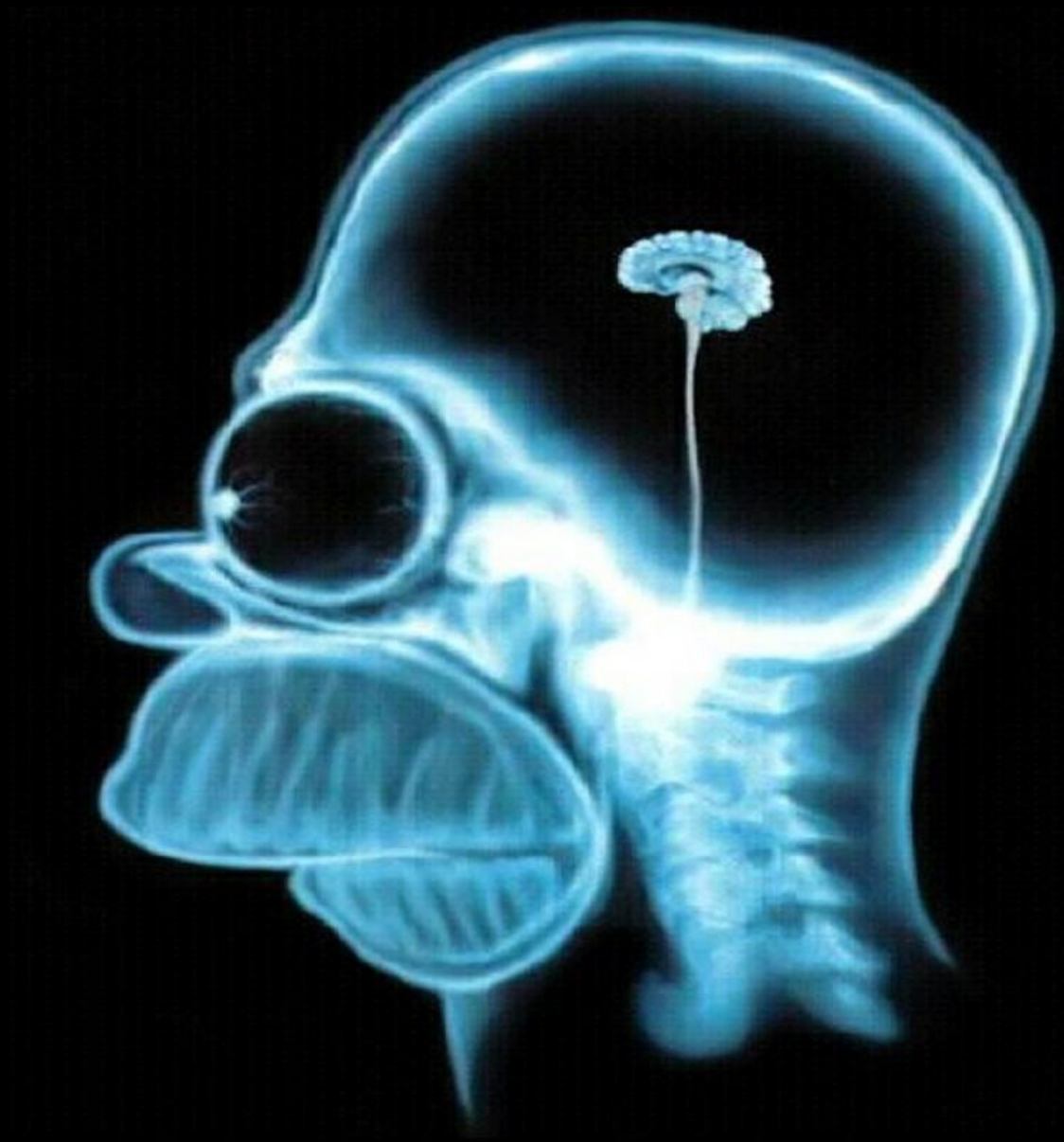
Color shift at depth



Actual colors observed

Your brain on high partial-pressure Nitrogen

Resolution
of
Case # 2



“ Don’t be a Statistic ”

7 ways for avoiding diving accidents

- Dive within the limits of your training.
- Get and use the right gear.
- Take a refresher course.
- Get rescue certified.
- Practice safety skills.
- Stay in shape for diving.
- Stay within your personal safety envelope.

Why learn to dive?

So many reasons…

- Spectacular marine life and environments

NATIONAL GEOGRAPHIC

Photograph by Patrik Gustafsson, National Geographic Your Shot

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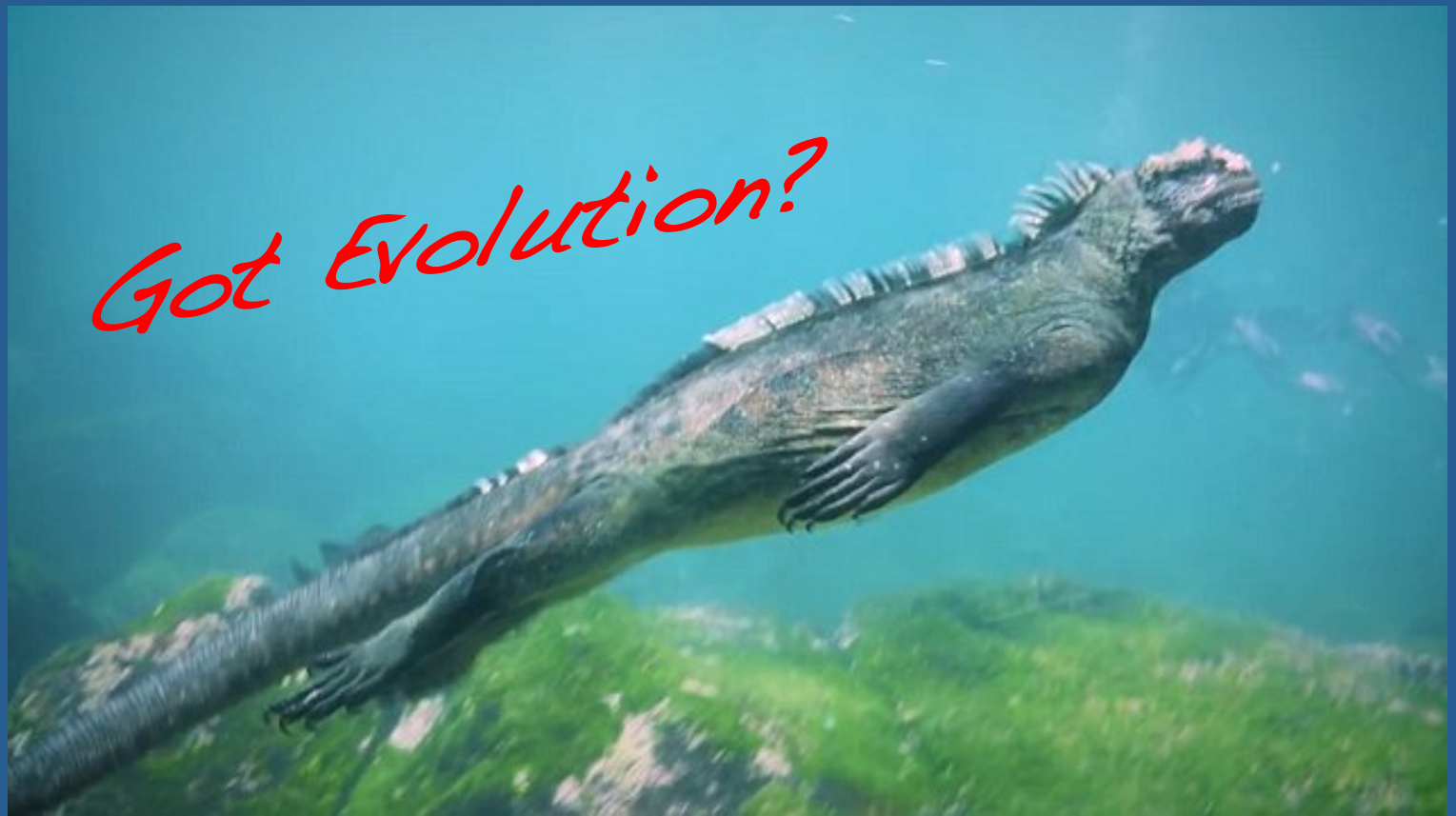

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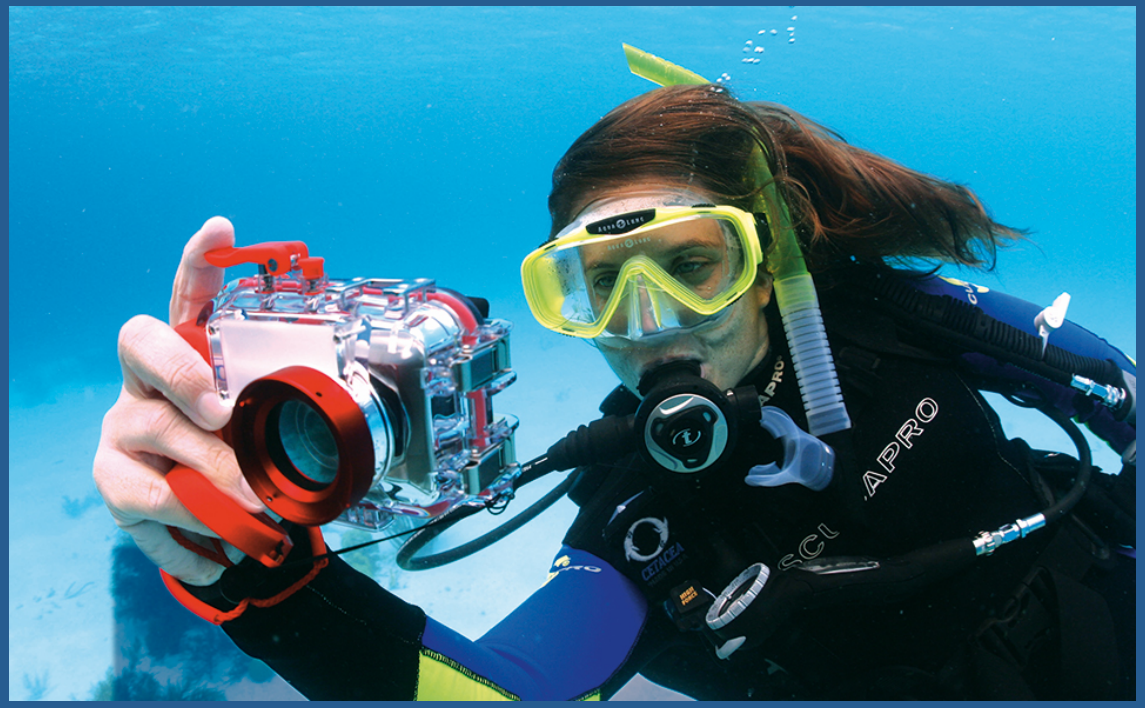

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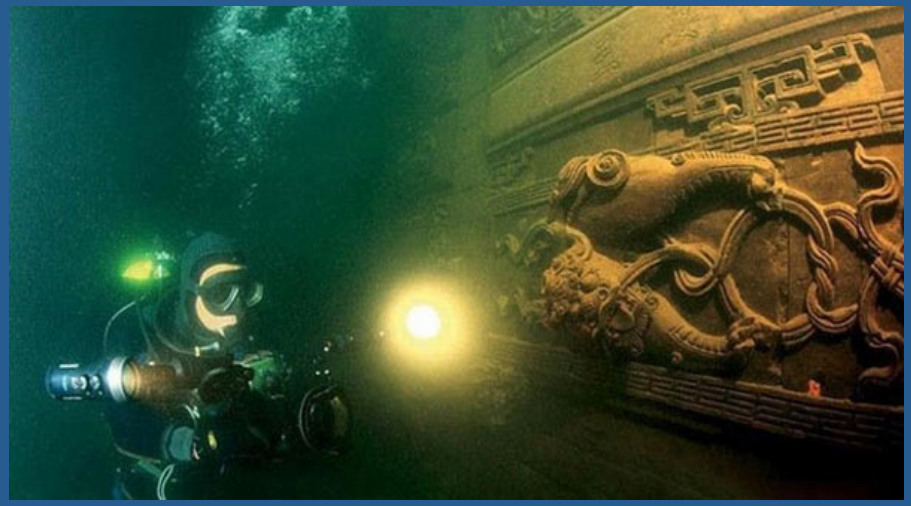

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- Underwater photography
- Marine archeology
- Sport spearfishing
- Wreck diving

Why learn to dive?

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- Marine biology
- Underwater photography
- Marine archeology
- Sport spearfishing
- Wreck diving
- Lake, Cave, River

Why learn to dive?

So many reasons…

- Spectacular marine life and environments
- Marine biology
- Underwater photo
- Marine archeology
- Sport spearfishing
- Wreck diving
- Lake, cave, and river..
- Get married

What did we learn this evening?

- Some history of diving and medicine.
- Some physics and physiology of diving.
- Some features of barotrauma.
- Your body and breathing compressed air.
- What happens with dissolved gases.
- How to stay safe and avoid injury.
- All the amazing things divers can do.


“ A good pilot (diver) is always training ”
Have fun !
Stay safe !
Have a
great adventure !

NATIONAL GEOGRAPHIC

Photograph by Patrik Gustafsson, National Geographic Your Shot