The Bends is an illness that arises from the rapid release of nitrogen gas from the bloodstream and is caused by bubbles forming in the blood and other tissues when a diver ascends to the surface of the ocean too rapidly. It is also referred to as Caisson sickness, decompression sickness (DCS), and Divers' Disease.

Introduction

As divers descend into the ocean, the external pressure on their bodies increases by about 1 atm every 10.06 m. To balance this it is necessary to increase the pressure of the air they breathe from tanks or pumped to them from the surface so that their chests and lungs do not collapse. Unfortunately, our bodies aren't used to the pressurized air (because we normally breathe air under normal atmospheric conditions). With higher air pressure in the lungs Henry's Law tells us that gases such as nitrogen, helium (when used in diving gas mixtures) and oxygen become increasingly soluble in the blood. Unlike oxygen which is metabolized, nitrogen and helium build up throughout the body. When divers want to emerge from the water, they have to make sure they don't ascend to the surface level too quickly because they risk numerous bubbles forming as the nitrogen/helium re-equilibrates, much as when a pressurized bottle of soda is suddenly opened. When nitrogen (N\textsubscript{2}) gas forms bubbles, it accumulates and saturates the muscles and blood, causing pain. Called the Bends, this condition can also cause injuries involving the nervous system.

![Image](https://example.com/image.jpg)

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The solubility of a gas is the ability for the gas to dissolve in a solvent (in our case, blood, which although it contains organic components is essentially an aqueous solution). Both temperature and pressure affect the solubility of a gas.

The Solubility as a Function of Temperature

- In water solvents, the higher the temperature, the less soluble the gas is.
- In organic solvents, the higher the temperature, the more soluble the gas is.

The Solubility as a Function of Pressure

English chemist William Henry discovered that as the pressure increases, the solubility of a gas increases. Henry's Law is then:

\[ C = k \text{P}_{\text{gas}} \]

where

- \( C \) = solubility of a gas in a solvent at a specific temperature,
• $P_{\text{gas}}$ is the partial pressure of the gas, and
• $k$ is Henry's Law Constant

In the case of The Bends:

• If a diver goes deeper and deeper into the water, more nitrogen builds up in the bloodstream and other tissues.
• Following Henry's Law; as the pressure increases, the solubility of nitrogen in the diver's bloodstream increases.
• As a result, nitrogen from the compressed air stays in the bloodstream and other tissues.
• However, since the diver is in a highly-pressurized environment, the excess $N_2$ can only be relieved when the diver ascends to levels with lower external pressure.
• Ideally, this should happen during the diver's gradual rise to the surface.
• Unfortunately, sometimes, the diver ascends too quickly, resulting in the rapid formation of bubbles, which interferes with nerves, blood and lymphatic vessels and leads to excruciating joint pain and clotting.

Example $\PageIndex{1}$:

Determine Henry's Law Constant, $k$, with the information that the aqueous solubility of $N_2$ at 10 degrees Celsius is 11.5 mL $N_2$ / L and 1 atm.

\[
k = \dfrac{11.5 \text{ mL } N_2 / L}{1 \text{ atm}}
\]

Now if the $P_{\text{gas}}$ of $N_2$ increases to 5 atm:

\[
\begin{align*}
5 \text{ atm} &= \dfrac{C}{\dfrac{11.5 \text{ mL } N_2 / L}{1 \text{ atm}}} \\
C &= 57.5 \text{ mL } N_2 / L
\end{align*}
\]

Therefore, both examples show that as the pressure increases from 1 atm to 5 atm, the solubility of the $N_2$ gas increases from 11.5 to 57.5 mL $N_2$ / L. This supports Henry's Law.

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**Symptoms of the Bends**

• Joint pain
• Fatigue
• Itching and rashes
• Coughing and chest pain
• Dizziness and paralysis
• Unconsciousness
• Death

Most symptoms occur 24 hours after decompression, but can occur up to 3 days after.
Prevention

• Ascending to the surface slowly (rate of 60 ft/min.)
  ◦ The slower the diver surfaces, the more slowly the excess nitrogen is equilibrated and the lower the impact on the diver
• Spending time in a decompression chamber
  ◦ Chambers that high-pressured divers are placed in.
  ◦ Once in the chamber, the diver is immersed in a high pressure environment which is slowly reduced, minimizing any effect.
• Breathing a compressed air mixture of helium and oxygen with no nitrogen.
  ◦ For deep dives, in addition to the Bends, excess nitrogen can lead to decreased mental function. This is called nitrogen narcosis.
  ◦ Helium is less soluble in the blood stream and thus does not build up as much, providing a smaller threat to divers and is used for deep dives.

References


Problems

1. What is Henry's law?
2. How does Henry's law relate to the Bends illness?
3. How does temperature affect solubility?
4. How does ascending to the surface make the bends less prevalent?
5. Why is breathing the compressed helium/oxygen mixture better than air with $N_2$?

Answers

1. \(C = k \cdot P_{\text{gas}}\) (where $C$=solubility of a gas in a solvent at a specific temperature, $P_{\text{gas}}$ is the partial pressure of the gas, and $k$ is Henry's Law Constant)
2. As the pressure increases, the solubility of gases in the diver's bloodstream increases. Henry's law states that the solubility of a gas increases when the pressure increases.
3. As temperature increases, the solubility of gases decrease in aqueous solutions. In organic solutions, the solubility of gases increases at higher temperatures.
4. When diver surfaces slowly, he/she will have a reduced impact of pain from the bubbles that form. Instead of rapidly forming and causing joint pain, the slow rise to the surface creates a steady loss of pressure, resulting in
pain that is not as severe.

5. Helium is less soluble in the blood stream, providing a smaller threat to divers when they come up to the surface of the ocean. Fewer bubbles are formed, meaning that the divers encounter less pain as they ascend.

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