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# CARBON DIOXIDE (CO<sub>2</sub>)

## NORMAL PHYSIOLOGY & HAZARDS AND RISKS

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### CO<sub>2</sub> IN NORMAL PHYSIOLOGY

In humans, carbon dioxide (CO<sub>2</sub>) is produced in cells as a byproduct of metabolism.<sup>1</sup> Then it circulates through the bloodstream, mostly within red blood cells, to be exhaled from the lungs as CO<sub>2</sub> and excreted from kidneys as bicarbonate (HCO<sub>3</sub><sup>-</sup>).

CO<sub>2</sub> levels:<sup>2</sup>

- play a major role in regulating blood and tissue pH (acid-base balance)
- largely determine respiratory drive (rate and depth of breathing)
- influence oxygen attachment to hemoglobin

Internal physiologic processes tightly regulate CO<sub>2</sub> levels in the blood; abnormally high concentrations cause a variety of signs and symptoms. (See CO<sub>2</sub> toxicity below.)

**Maintaining blood pH within a narrow range is essential for normal functioning of virtually all organs and physiologic systems.** CO<sub>2</sub> plays a central role via these reactions:



where H<sub>2</sub>O is water, H<sub>2</sub>CO<sub>3</sub> is carbonic acid; HCO<sub>3</sub><sup>-</sup> is bicarbonate; H<sup>+</sup> is hydrogen ion.

Humans and virtually every living organism (plants and animals) have evolved to produce an enzyme, carbonic anhydrase<sup>3</sup>, which dramatically increases the speed of the first part of the above reaction, (CO<sub>2</sub> + H<sub>2</sub>O ↔ H<sub>2</sub>CO<sub>3</sub>), making this an ideal system for very rapidly fine-tuning the regulation of CO<sub>2</sub> levels and blood pH through changes in the rate and depth of respiration.

CO<sub>2</sub> also reacts with water to form carbonic acid in a CO<sub>2</sub> pipeline, even in the absence of carbonic anhydrase, albeit much more slowly. Carbonic acid is highly corrosive to carbon steel.

The main drivers of respiratory rate and depth are normally bloodstream CO<sub>2</sub> levels and associated pH changes. These are maintained within healthy limits by chemoreceptors located in the medulla at the base of the brain (central chemoreceptors) and in the aorta and carotid arteries (peripheral chemoreceptors). Brain receptors detect changes in the CO<sub>2</sub> and pH, aorta receptors detect changes in CO<sub>2</sub> and oxygen, and carotid receptors detect changes in all three. Respiratory rate and depth increase primarily in response to an increase in CO<sub>2</sub>/decrease in pH to reduce CO<sub>2</sub> and maintain pH within normal limits.

## **CO<sub>2</sub>: AN ASPHYXIANT AND TOXICANT**

CO<sub>2</sub> is colorless, odorless, non-flammable, and heavier than air. As a gas in air, concentrations will be higher near the floor or ground. It can be compressed at high pressures into a liquid or frozen at very low temperatures into a solid (dry ice).

**CO<sub>2</sub> is classified as a hazardous substance** by the Occupational Safety and Health Administration (OSHA) and National Institute for Occupational Safety and Health (NIOSH)<sup>4</sup>

### **Workplace exposure limits:**

OSHA: Airborne permissible exposure limit (PEL) is 5000 ppm (0.5%) averaged over 8 hours.

NIOSH: Recommended airborne exposure limit (REL) is 5000 ppm averaged over 10 hours and not to exceed 30,000 ppm (3%) over any 15 minute period.

Ambient air contains about 0.04% (400 ppm) CO<sub>2</sub>, 20% O<sub>2</sub>, 79% nitrogen, and small amounts of other gases.

This air level of CO<sub>2</sub> has no direct adverse health effects in humans. As a potent greenhouse gas, however, this steadily-increasing atmospheric concentration is a major driver of climate change, which has wide-ranging direct and indirect health impacts globally.

Inhalation exposures to concentrations of CO<sub>2</sub> higher than OSHA and NIOSH exposure limits are hazardous in two ways, both of which contribute to signs and symptoms (see also table next page):

- Gaseous CO<sub>2</sub> is heavier than air and when released in concentrated amounts it flows downhill, collects in low-lying areas—indoors or outdoors—or confined, poorly-ventilated spaces such as basements, storage tanks, dry-ice refrigeration systems, fermentation areas, or mines. It displaces ambient air so that oxygen levels can fall to dangerously low levels. For that reason, CO<sub>2</sub> is well-known as an asphyxiant.

- CO<sub>2</sub> also has toxic properties in addition to causing oxygen-deprivation. Inhalation of high concentrations of CO<sub>2</sub> can sharply lower the pH of blood and tissues (acidosis) causing acute effects on the respiratory, cardiovascular, and central nervous systems.

The response to excessive CO<sub>2</sub> inhalation varies even among healthy individuals<sup>5</sup> so that the timing of onset of signs and symptoms of toxicity can vary from one person to another. This may be due to underlying health status, age, or variability in chemoreceptor sensitivity and respiratory response to acute CO<sub>2</sub> exposures.

Symptoms depend in large part on the concentration of inhaled CO<sub>2</sub> and the length of time a person is exposed. Since CO<sub>2</sub> is odorless and does not cause irritation, unlike some other gases, it gives no warning and people may be unaware of excessive exposures until they experience troubling, dangerous symptoms.

## CO<sub>2</sub> TOXICITY<sup>6</sup>

CO <sub>2</sub> Concentration	Health Effect	Timing
2% (20,000 ppm)	Respiratory center stimulated causing increases in breathing (tidal) volume	Rapid
4% (40,000 ppm)	Increase in breathing rate becomes distressing; development of respiratory acidosis	Immediately dangerous to life and health (IDLH) [NIOSH] *
5-10%	Dimmed sight, sweating, tremor, increased heart rate and blood pressure; can → unconsciousness**	Within a few minutes
More than 10%	Can cause convulsions; coma (less than one minute)	Death within 10 minutes
20-30%	Loss of consciousness; death	Within one minute

\* NIOSH considers this level to be immediately dangerous to life and health because it can cause confusion and impair ability to respond and get to safety. Signs and symptoms resulting from low to moderate exposures are generally reversible when a person is removed from a high CO<sub>2</sub> environment.

\*\* Symptoms are due to a combination of lower oxygen levels and CO<sub>2</sub> toxicity.<sup>7</sup>

## REFERENCES

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