

What you need to know about the carbon cycle, atmosphere –ocean CO₂ interactions and climate change

I The carbon cycle reactions (part of the biological pump)

Important reactions

Photosynthesis: $\text{CO}_{2(\text{aq})} + \text{H}_2\text{O} \rightarrow \text{CH}_2\text{O} + \text{O}_2$ (this is the BIO PUMPing “formation” reaction!!!)

Respiration $\text{CH}_2\text{O} + \text{O}_2 \rightarrow \text{CO}_{2(\text{aq})} + \text{H}_2\text{O}$ (The BIO PUMP sequesters CO₂ when organic matter sinks and is respired)

The above reactions move carbon back and forth between the organic reservoir and the inorganic reservoir.

II The carbonate system

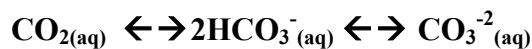
When the carbon is in its inorganic phase (CO₂) then we must consider the carbonate family and its reactions:

- 1 $\text{CO}_{2(\text{aq})} + \text{H}_2\text{O} \leftrightarrow \text{H}_2\text{CO}_{3(\text{aq})}$ (carbonic acid)
- 2 $\text{H}_2\text{CO}_{3(\text{aq})} \leftrightarrow \text{H}^+_{(\text{aq})} + \text{HCO}_3^-_{(\text{aq})}$ (bicarbonate ion)
- 3 $\text{HCO}_3^-_{(\text{aq})} \leftrightarrow \text{H}^+_{(\text{aq})} + \text{CO}_3^{-2}_{(\text{aq})}$ (carbonate ion)
- 4 $\text{Ca}^{++}_{(\text{aq})} + \text{CO}_3^{-2}_{(\text{aq})} \leftrightarrow \text{CaCO}_3$ (calcium carbonate mineral)

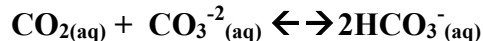
Reactions 1-3 describe the dissolved system reaction 4 is the formation of the solid, CaCO₃ “limestone”

A) For the dissolved phases:

This is a buffered reaction and bi-carbonate is favored at ocean pH. Thus the sum reaction of the dissolved species moves towards bicarbonate at all times. So the important summary equation for the dissolved ΣCO_2 is :



Also written as



This signifies if carbon dioxide is added CO₃⁻² is consumed in the transformation to HCO₃⁻. The consequence is that calcium carbonate dissolves or is harder to precipitate.

And the governing equilibrium constant is:

$$K^1 = \frac{[\text{CO}_{2(\text{aq})}][\text{CO}_3^{-2}]}{[\text{HCO}_3^-]^2}$$

What does this mean? It means that more CO₂ added to the water does NOT stay as CO₂ it dissociates to and on short(ish) timescales the reaction has 3 consequences –

- lots of carbon is dissolved in the ocean as bicarbonate (the ocean sequesters CO₂)
- the pH of the ocean decreases (ocean acidification)
- carbonate ion is disfavored – there is proportionally less CO₃⁻² because of this:
 - the formation of CaCO₃ is also disfavored.

B) The solid phase: (the carbonate pump, and sediment connection)

The above equation #4 is the condensed of what is 2 steps within the organism

- a. $2\text{HCO}_3^-_{(\text{aq})} \rightarrow 2\text{CO}_3^{-2}_{(\text{aq})} + 2\text{H}^+ \rightarrow$ (bicarbonate is taken up and converted to carbonate)
- b. $\text{Ca}^{++}_{(\text{aq})} + 2\text{CO}_3^{-2}_{(\text{aq})} + 2\text{H}^+ \leftrightarrow \text{CaCO}_3 + \text{CO}_2 + \text{H}_2\text{O}$ (calcium carbonate mineral)
- c. Ω is the saturation state and is governed by:

$$\Omega = \frac{[\text{Ca}^{++}][\text{CO}_3^{-2}]}{K'_{\text{sp}}}$$