How carbon dioxide lowers ocean pH

Ocean acidification is a sustained decrease in seawater pH, driven mainly by uptake of additional atmospheric carbon dioxide. Dissolving CO2 changes the balance among dissolved carbon species.

1. FOLLOW THE AQUEOUS CHEMISTRY

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

Dissolved carbon dioxide reacts with water to form carbonic acid. Only part of the dissolved CO_2 is present as carbonic acid.

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

Carbonic acid can release a hydrogen ion and form bicarbonate. An increase in hydrogen ion concentration lowers pH. H^+ is conventional shorthand for a hydrated hydrogen ion in water.

The paired arrows mean reversible equilibria, not complete one-way conversion. Adding CO_2 shifts the chemical balance; seawater buffering limits the change but does not prevent acidification.

2. LINK THE CHEMISTRY TO HUMAN ACTIVITIES

Fossil-fuel combustion in power generation, industry and vehicles adds CO_2 to the atmosphere. Deforestation can release stored carbon and reduce uptake by trees. Higher atmospheric CO_2 drives additional ocean uptake, linking land-based activities to changes in seawater.

3. ACIDIFICATION DOES NOT REQUIRE pH BELOW 7

A shift from pH 8.2 to 8.1 is acidification even though both values are above 7. The water becomes less basic: the word describes the direction of change, not a requirement to cross neutral pH.

Carbon species and chemical reactions: NOAA Ocean Acidification Program.
pH, buffering and human causes: WHOI, FAQs about Ocean Acidification.

Scope: College Board APES CED, Topic 9.7, STB-4.H.1-4, p. 189.

Why carbonate becomes less available

Carbonate ions are ingredients for calcium carbonate shells and skeletons. Added CO2 can increase total dissolved inorganic carbon while decreasing the carbonate portion; more carbon does not mean more carbonate.

1. HYDROGEN IONS CONSUME CARBONATE

$$H^+ + CO_3^{2-} \rightleftharpoons HCO_3^-$$

Hydrogen ions combine with carbonate to form bicarbonate. As added CO_2 changes this balance, carbonate availability falls. Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) are different ions.

2. CALCIFICATION NEEDS THE RIGHT INGREDIENTS

$$Ca^{2+} + CO_3^{2-} \rightleftharpoons CaCO_3\,(s)$$

This simplified equilibrium represents formation or dissolution of solid calcium carbonate; (s) means solid. Lower carbonate availability reduces the tendency for this mineral to form. Calcium ions have not simply disappeared from the sea.

3. CONNECT CHEMISTRY TO BIOLOGICAL COST

LESS CARBONATE

Building mineral structures becomes more difficult.

→

HIGHER COST

Organisms may spend more energy maintaining shells.

→

ECOLOGICAL EFFECT

Growth, survival or reproduction can decline.

Existing structures may dissolve when water becomes undersaturated with respect to their mineral. Acidification does not mean every shell instantly dissolves: mineral type, local chemistry and organism biology affect the response.

Carbonate consumption and calcification: NOAA Atlantic Oceanographic Laboratory.
Mineral saturation, dissolution and biological responses: WHOI, Ocean Acidification FAQs.

Scope: College Board APES CED, Topic 9.7, STB-4.H.1-4, p. 189.

From smaller shells to reef change

Calcifying organisms build calcium carbonate structures. Corals, oysters, clams and some plankton can be affected, but sensitivity varies among species and life stages; not all marine organisms respond identically.

1. CORALS: SKELETON BUILDING AND REEF GROWTH

Corals build calcium carbonate skeletons, not shells in the same sense as oysters. Reduced calcification and increased erosion can weaken reef frameworks. Loss of reef complexity can reduce shelter for other species and affect coastal protection, fisheries and tourism.

2. SHELLFISH AND FOOD WEBS

Shell-building can become more difficult for shellfish, including sensitive early life stages. Changes in growth or survival can affect populations, aquaculture and harvests. Impacts on calcifying plankton may also alter food available to their consumers; food-web outcomes depend on the species involved.

3. DO NOT CONFUSE ACIDIFICATION WITH BLEACHING

Acidification: dissolved CO_2 changes carbonate chemistry, making skeleton formation and maintenance harder.

Heat-driven bleaching: temperature stress disrupts the coral-algal partnership, causing loss of symbiotic algae and color. Both pressures can act on the same reef.

4. ADDRESS THE CAUSE AND REDUCE LOCAL STRESS

Reducing CO_2 emissions tackles the main global driver; energy efficiency and lower-carbon energy can help. Protecting forests supports carbon uptake. Limiting nutrient pollution and habitat damage can reduce additional local pressure, but does not substitute for reducing atmospheric CO_2.

Calcifiers and food webs: NOAA, What Is Ocean Acidification?
Corals and shellfish: NOAA Ocean Acidification Program, Biological Response.
Acidification versus heat stress: NOAA, Climate Change Threats to Corals.
Responses and limitations: WHOI, FAQs about Ocean Acidification.

Scope: College Board APES CED, Topic 9.7, STB-4.H.1-4, p. 189.