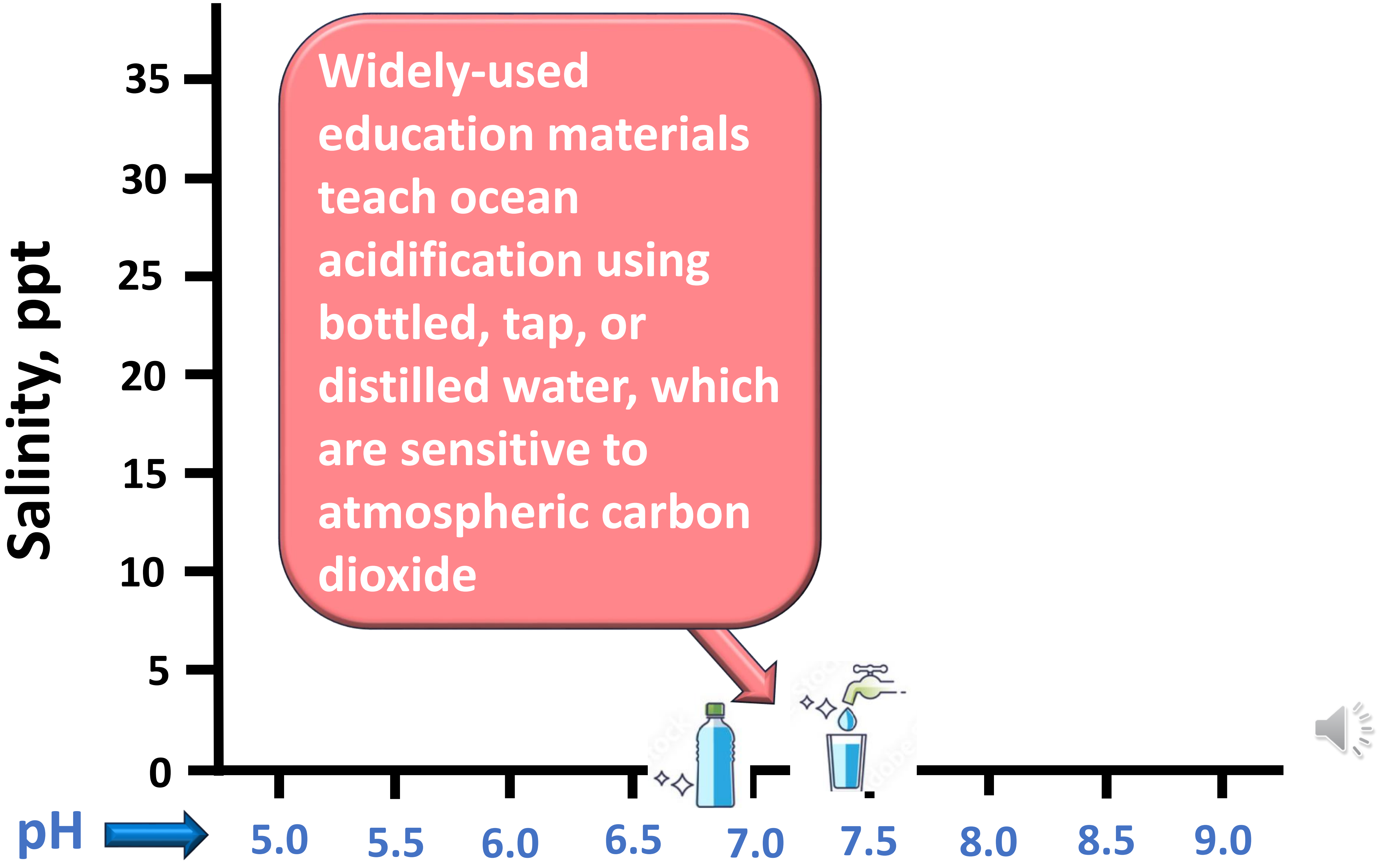
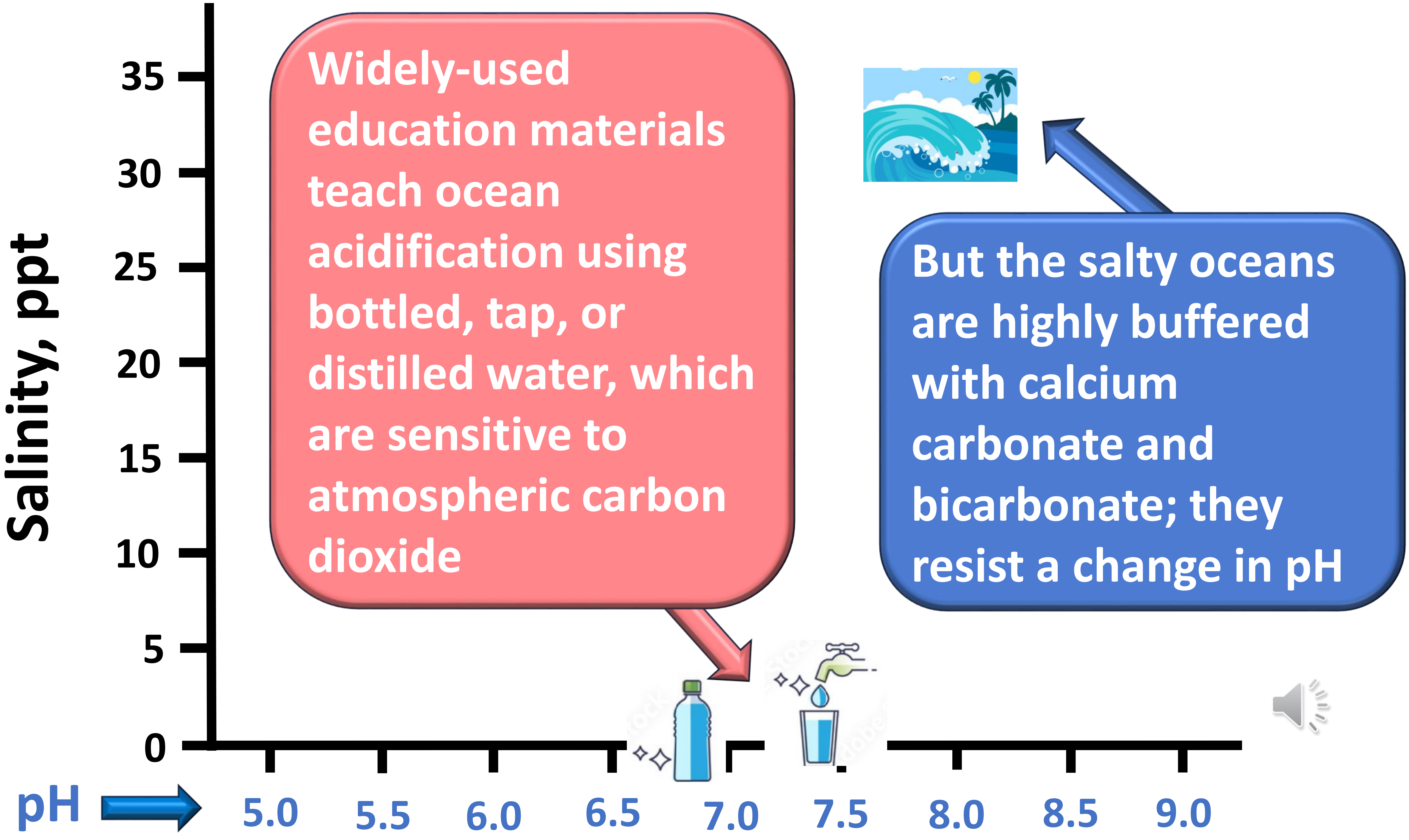
CO2 LEARNING CENTER

An Experiment in Ocean Acidification: Why Buffering Matters

This presentation supports the CO_2 Learning Center Lesson Plan *Ocean Acidification: Why Buffering Matters,* designed for grades 8-12.


Salinity, ppt
35
30
25
20
15
10
5
0
pH
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
Widely-used education materials teach ocean acidification using bottled, tap, or distilled water, which are sensitive to atmospheric carbon dioxide


Salinity, ppt
35
30
25
20
15
10
5
0
pH
5.0
5.5
6.0
6.5
7.0
7.5
8.0
8.5
9.0
Widely-used education materials teach ocean acidification using bottled, tap, or distilled water, which are sensitive to atmospheric carbon dioxide
But the salty oceans are highly buffered with calcium carbonate and bicarbonate; they resist a change in pH

Reviews of Geophysics

REVIEW ARTICLE
10.1029/2019RG000681

Ocean Alkalinity, Buffering and Biogeochemical Processes

Jack J. Middelburg[1], Karline Soetaert[2], and Mathilde Hagens[3]

"Seawater is a solution with multiple weak acids and bases in contact with both the atmosphere and sediments containing minerals that have the potential to react when solution composition or physical conditions change. **Seawater is consequently well buffered**…"

ADVANCING EARTH AND SPACE SCIENCE

Reviews of Geophysics

REVIEW ARTICLE
10.1029/2019RG000681

Ocean Alkalinity, Buffering and Biogeochemical Processes

Jack J. Middelburg[1], Karline Soetaert[2], and Mathilde Hagens[3]

"Seawater is a solution with multiple weak acids and bases in contact with both the atmosphere and sediments containing minerals that have the potential to react when solution composition or physical conditions change. **Seawater is consequently well buffered**…"

A buffered solution resists changes to pH

pH of Ocean Water (Alkalinity 2.3×10^{-3} M, 25 °C)

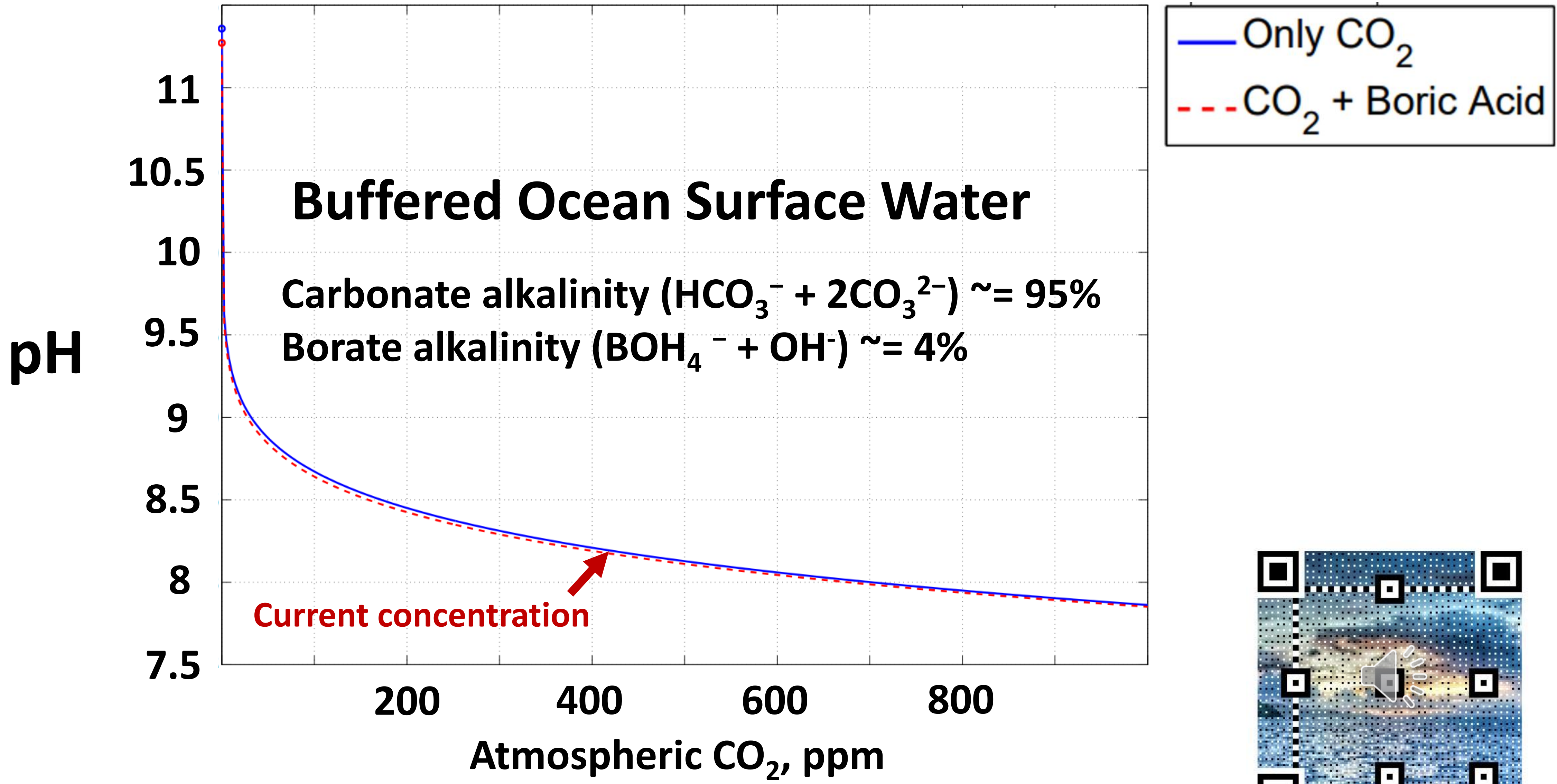


Figure from *Fundamentals of Ocean pH*, R. Cohen and W. Happer, Sept. 18, 2015

Ocean "Acidification" of Buffered Sea Water

Materials

- ✓ Sea salts
- ✓ Distilled water
- ✓ Hydrometer
- ✓ Four 8-oz clear cups
- ✓ Measuring cup
- ✓ Antacid tablets
- ✓ Bromothymol blue
- ✓ BTB pH color chart
- ✓ CO_2 meter
- ✓ Labels
- ✓ Jug, e.g. ½ gallon
- ✓ Translucent container with sealable lid
- ✓ Aluminum foil*

* Placing a sheet of foil between the container and lid will better seal and preserve high CO_2 level

Ocean "Acidification" of Buffered Sea Water

Materials

- ✓ Sea salts
- ✓ Distilled water
- ✓ Hydrometer
- ✓ Four 8-oz clear cups
- ✓ Measuring cup
- ✓ Antacid tablets
- ✓ Bromothymol blue
- ✓ BTB pH color chart
- ✓ CO_2 meter
- ✓ Labels
- ✓ Jug, e.g. ½ gallon
- ✓ Translucent container with sealable lid
- ✓ Aluminum foil*

* Placing a sheet of foil between the container and lid will better seal and preserve high CO_2 level

Ocean "Acidification" of Buffered Sea Water

Materials

- ✓ Sea salts
- ✓ Distilled water
- ✓ Hydrometer
- ✓ Four 8-oz clear cups
- ✓ Measuring cup
- ✓ Antacid tablets
- ✓ Bromothymol blue
- ✓ BTB pH color chart
- ✓ CO_2 meter
- ✓ Labels
- ✓ Jug, e.g. ½ gallon
- ✓ Translucent container with sealable lid
- ✓ Aluminum foil*

* Placing a sheet of foil between the container and lid will better seal and preserve high CO_2 level

Ocean "Acidification" of Buffered Sea Water

Materials

- ✓ Sea salts
- ✓ Distilled water
- ✓ Hydrometer
- ✓ Four 8-oz clear cups
- ✓ Measuring cup
- ✓ Antacid tablets
- ✓ Bromothymol blue
- ✓ BTB pH color chart
- ✓ CO_2 meter
- ✓ Labels
- ✓ Jug, e.g. ½ gallon
- ✓ Translucent container with sealable lid
- ✓ Aluminum foil*

* Placing a sheet of foil between the container and lid will better seal and preserve high CO_2 level

Ocean "Acidification" of Buffered Sea Water

Materials

- ✓ Sea salts
- ✓ Distilled water
- ✓ Hydrometer
- ✓ Four 8-oz clear cups
- ✓ Measuring cup
- ✓ Antacid tablets
- ✓ Bromothymol blue
- ✓ BTB pH color chart
- ✓ CO_2 meter
- ✓ Labels
- ✓ Jug, e.g. ½ gallon
- ✓ Translucent container with sealable lid
- ✓ Aluminum foil*

* Placing a sheet of foil between the container and lid will better seal and preserve high CO_2 level

Ocean "Acidification" of Buffered Sea Water

Materials

- ✓ Sea salts
- ✓ Distilled water
- ✓ Hydrometer
- ✓ Four 8-oz clear cups
- ✓ Measuring cup
- ✓ Antacid tablets
- ✓ Bromothymol blue
- ✓ BTB pH color chart
- ✓ CO_2 meter
- ✓ Labels
- ✓ Jug, e.g. ½ gallon
- ✓ Translucent container with sealable lid
- ✓ Aluminum foil*

* Placing a sheet of foil between the container and lid will better seal and preserve high CO2 level

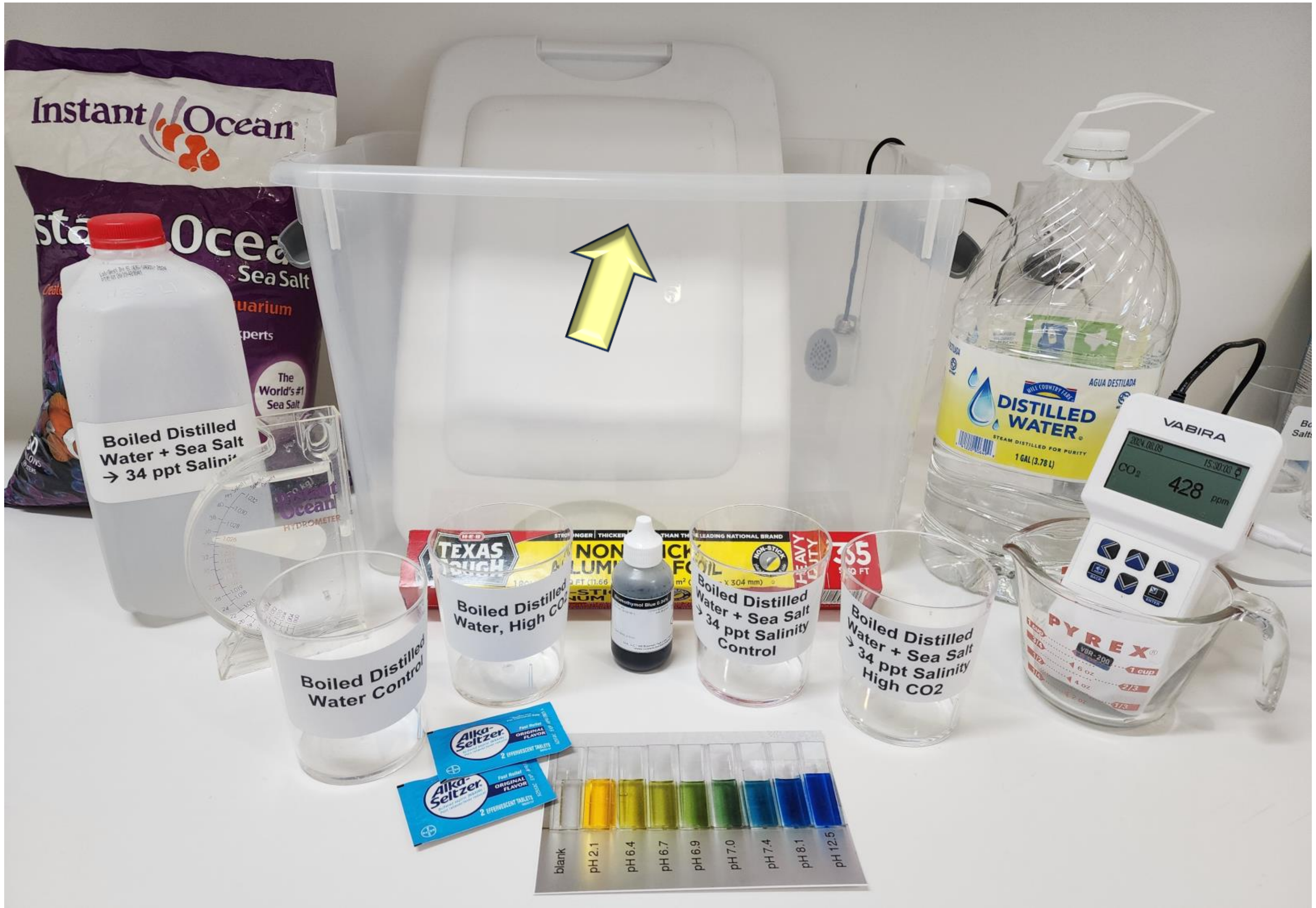
Ocean "Acidification" of Buffered Sea Water

Materials

- ✓ Sea salts
- ✓ Distilled water
- ✓ Hydrometer
- ✓ Four 8-oz clear cups
- ✓ Measuring cup
- ✓ Antacid tablets
- ✓ Bromothymol blue
- ✓ BTB pH color chart
- ✓ CO_2 meter
- ✓ Labels
- ✓ Jug, e.g. ½ gallon
- ✓ Translucent container with sealable lid
- ✓ Aluminum foil*

* Placing a sheet of foil between the container and lid will better seal and preserve high CO_2 level

Ocean “Acidification” of Buffered Sea Water



Materials

- ✓ Sea salts
- ✓ Distilled water
- ✓ Hydrometer
- ✓ Four 8-oz clear cups
- ✓ Measuring cup
- ✓ Antacid tablets
- ✓ Bromothymol blue
- ✓ BTB pH color chart
- ✓ CO_2 meter
- ✓ Labels
- ✓ Jug, e.g. ½ gallon
- ✓ Translucent container with sealable lid
- ✓ Aluminum foil*

* Placing a sheet of foil between the container and lid will better seal and preserve high CO_2 level

Ocean "Acidification" of Buffered Sea Water

Materials

- ✓ Sea salts
- ✓ Distilled water
- ✓ Hydrometer
- ✓ Four 8-oz clear cups
- ✓ Measuring cup
- ✓ Antacid tablets
- ✓ Bromothymol blue
- ✓ BTB pH color chart
- ✓ CO_2 meter
- ✓ Labels
- ✓ Jug, e.g. ½ gallon
- ✓ Translucent container with sealable lid
- ✓ Aluminum foil*

* Placing a sheet of foil between the container and lid will better seal and preserve high CO_2 level

Ocean "Acidification" of Buffered Sea Water

Materials

- ✓ Sea salts
- ✓ Distilled water
- ✓ Hydrometer
- ✓ Four 8-oz clear cups
- ✓ Measuring cup
- ✓ Antacid tablets
- ✓ Bromothymol blue
- ✓ BTB pH color chart
- ✓ CO_2 meter
- ✓ Labels
- ✓ Jug, e.g. ½ gallon
- ✓ Translucent container with sealable lid
- ✓ Aluminum foil*

* Placing a sheet of foil between the container and lid will better seal and preserve high CO_2 level

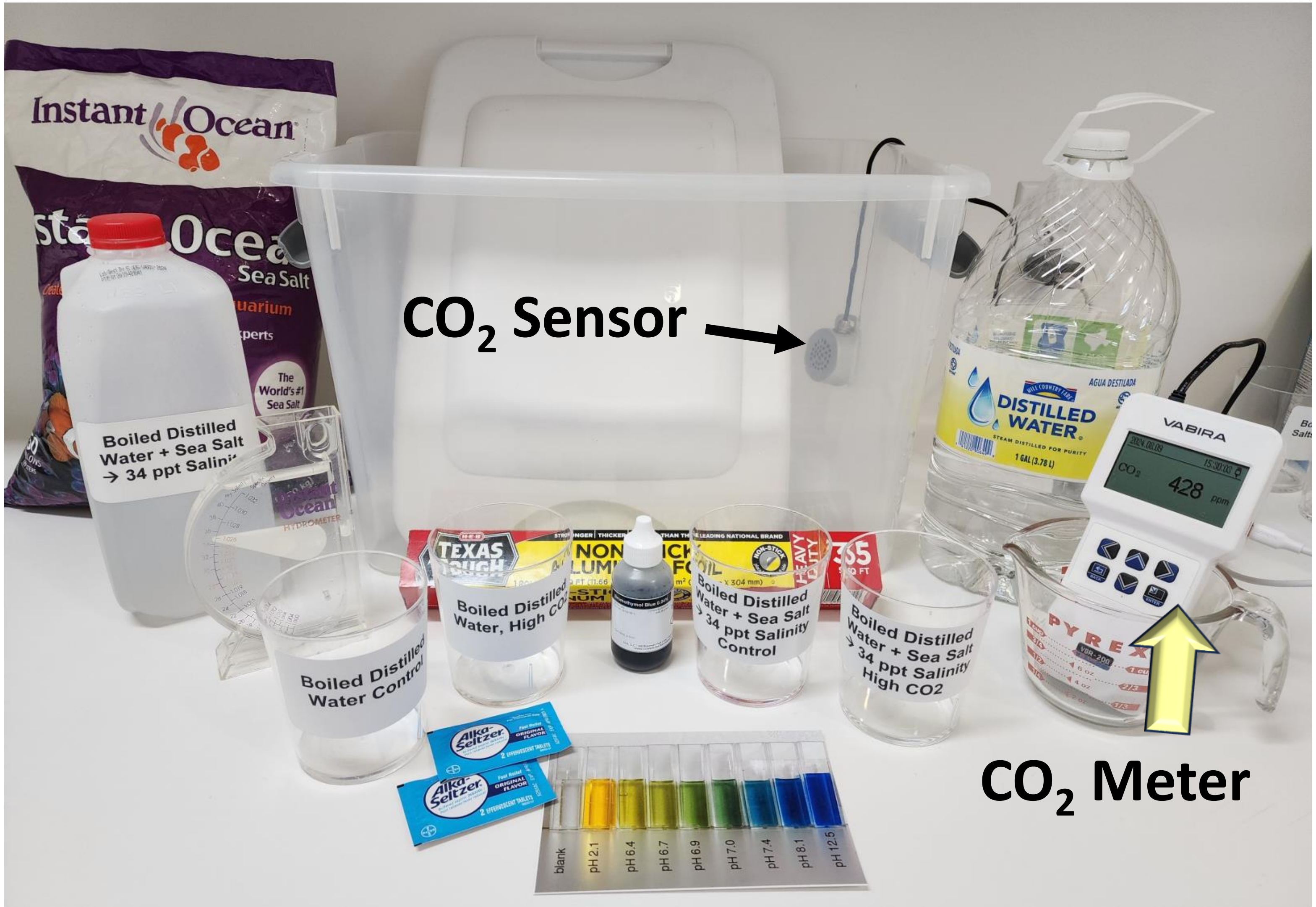
Ocean "Acidification" of Buffered Sea Water

Materials

- ✓ Sea salts
- ✓ Distilled water
- ✓ Hydrometer
- ✓ Four 8-oz clear cups
- ✓ Measuring cup
- ✓ Antacid tablets
- ✓ Bromothymol blue
- ✓ BTB pH color chart
- ✓ CO_2 meter
- ✓ Labels
- ✓ Jug, e.g. ½ gallon
- ✓ Translucent container with sealable lid
- ✓ Aluminum foil*

* Placing a sheet of foil between the container and lid will better seal and preserve high CO_2 level

Ocean "Acidification" of Buffered Sea Water



Materials

- ✓ Sea salts
- ✓ Distilled water
- ✓ Hydrometer
- ✓ Four 8-oz clear cups
- ✓ Measuring cup
- ✓ Antacid tablets
- ✓ Bromothymol blue
- ✓ BTB pH color chart
- ✓ CO_2 meter
- ✓ Labels
- ✓ Jug, e.g. ½ gallon
- ✓ Translucent container with sealable lid
- ✓ Aluminum foil*

* Placing a sheet of foil between the container and lid will better seal and preserve high CO_2 level

Experimental Procedure

Step 1

Boil distilled water to remove residual carbonization, and cool.

Initial color of 200 ml distilled water with 40 drops bromothymol blue

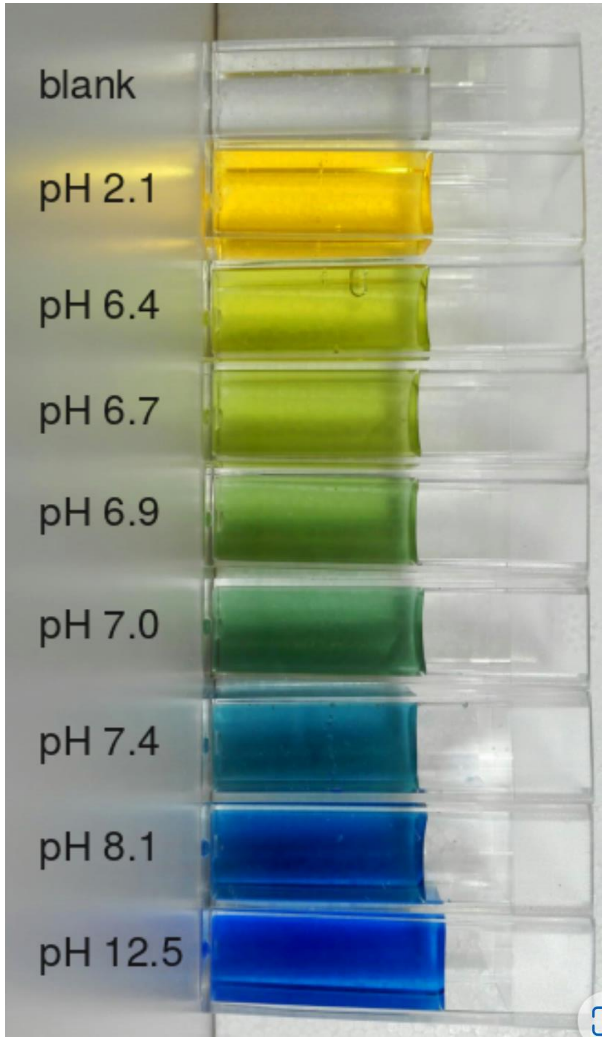


Photo from [Bromothymol blue colors at different pH - Bromothymol blue - Wikipedia]

Experimental Procedure

Step 1

Boil and cool ~ ½ gallon of distilled water to remove residual carbonization.

Step 2

Prepare a solution of sea water by adding ~$^{1}/_{4}$ cup of aquarium sea salts to a ½ gallon jug, then fill the jug half full with boiled distilled water. Using a hydrometer, adjust the salt content to 34 ppt salinity.

Experimental Procedure

Step 1 Boil and cool ~ ½ gallon of distilled water water to remove residual carbonization.

Step 2 Prepare a solution of sea water by adding ~$^{1}/_{4}$ cup of aquarium sea salts to a ½ gallon jug, then fill the jug half full with boiled distilled water. Using a hydrometer, adjust the salt content to 34 ppt salinity.

Step 3

Label each cup:

- **Boiled Distilled Water Control**
- **Boiled Distilled Water High CO_2**
- **Distilled Water + Sea Salts → 34 ppt Salinity Control**
- **Distilled Water + Sea Salts → 34 ppt Salinity High CO_2**

Step 4 **Add 200 ml of the appropriate water to each cup**

Experimental Procedure

Step 1 Boil and cool ~ ½ gallon of distilled water water to remove residual carbonization.

Step 2 Prepare a solution of sea water by adding ~$^{1}/_{4}$ cup of aquarium sea salts to a ½ gallon jug, then fill the jug half full with boiled distilled water. Using a hydrometer, adjust the salt content to 34 ppt salinity.

Step 3 Label each cup:

- Boiled Distilled Water Control
- Boiled Distilled Water High CO_2
- Distilled Water + Sea Salts → 34 ppt Salinity Control
- Distilled Water + Sea Salts → 34 ppt Salinity High CO_2

Step 4 Add 200 ml of the appropriate water to each cup

Step 5 **Add 40 drops of bromothymol blue to each cup and stir to mix.**

Experimental Procedure

Step 6

Record the pH color of the two solutions at the start of the experiment using the bromothymol blue color chart

Experimental Procedure

Step 7

Record the ambient air CO_2 content in the room. Because human breath will increase the CO_2 reading, this is best done before the room is filled with students.

Ambient Room Air

Experimental Procedure

Step 8

Position the sensor of the CO_2 meter on an inside wall or floor of the container.

Experimental Procedure

Step 9

Place the two cups labeled "High CO_2" and the measuring cup filled with ~300 ml of tap water inside the container. Add two antacid tablets to the water-filled measuring cup.

Experimental Procedure

Step 10

Placing a sheet of aluminum foil over the container before adding the lid will provide a tighter seal and preserve elevated CO_2 at >5,000 ppm for several hours.

Experimental Procedure

4 Hrs. at >5,000 ppm CO_2

Step 11

Note change of color of sample exposed to high CO_2 level with time

Experimental Procedure

Step 12

After recording the results, return the "High CO_2" sample to the container, replace the water in the measuring cup, add two antacid tablets, and seal the container with a fresh sheet of aluminum foil and the lid.

Note: During the experiment, replace the water in the measuring cup, adding two antacid tablets and fresh foil anytime the CO_2 reading drifts below 5,000 ppm.

Experimental Procedure

24 Hrs. at >5,000 ppm CO_2

Step 11

Note change of color of sample exposed to high CO_2 levels with time

>5,000 ppm CO_2 Exposure

0 hrs.

Unbuffered ~7.0 pH

Buffered ~8.1 pH

4 hrs.

Unbuff control ~6.9 pH

Unbuff High CO_2 ~ <<6.4 pH

Buffered ~8.1 pH

16 hrs.

Unbuff control ~6.7 pH

Unbuff High CO_2 ~ <<6.4 pH

Buffered High CO_2 7.4 pH

Buffered control ~8.1 pH

24 hrs.

Unbuff control ~6.4 pH

Unbuff High CO_2 ~ <<6.4 pH

Buffered High CO_2 ~ 7.4 pH

Buffered control ~8.1 pH

>5,000 ppm CO_2 Exposure

0 hrs. — Unbuffered ~7.0 pH

4 hrs. — Unbuff control ~6.9 pH

16 hrs. — Unbuff control ~6.7 pH

24 hrs. — Unbuff control ~6.4 pH

>5,000 ppm CO_2 Exposure

0 hrs.

4 hrs.

16 hrs.

24 hrs.

Unbuffered ~7.0 pH

Unbuff control ~6.9 pH
Unbuff High CO_2 ~ <<6.4 pH

Unbuff control ~6.7 pH
Unbuff High CO_2 ~ <<6.4 pH

Unbuff control ~6.4 pH
Unbuff High CO_2 ~ <<6.4 pH

>5,000 ppm CO_2 Exposure

0 hrs.

Unbuffered ~7.0 pH
Buffered ~8.1 pH

4 hrs.

Unbuff control ~6.9 pH
Unbuff High CO_2 ~ <<6.4 pH
Buffered ~8.1 pH

16 hrs.

Unbuff control ~6.7 pH
Unbuff High CO_2 ~ <<6.4 pH
Buffered High CO_2 ~ 7.4 pH

24 hrs.

Unbuff control ~6.4 pH
Unbuff High CO_2 ~ <<6.4 pH
Buffered High CO_2 ~ 7.4 pH

>5,000 ppm CO_2 Exposure

0 hrs.

Unbuffered ~7.0 pH
Buffered ~8.1 pH

4 hrs.

Unbuff control ~6.9 pH
Unbuff High CO_2 ~ <<6.4 pH
Buffered ~8.1 pH

16 hrs.

Unbuff control ~6.7 pH
Unbuff High CO_2 ~ <<6.4 pH
Buffered High CO_2 ~ 7.4 pH
Buffered control ~8.1 pH

24 hrs.

Unbuff control ~6.4 pH
Unbuff High CO_2 ~ <<6.4 pH
Buffered High CO_2 ~ 7.4 pH
Buffered control ~8.1 pH

Experimental Conclusions

- **The degassed distilled water control demonstrates how easily water absorbs CO_2. This is true for both fresh and salt water. In the case of our freshwater control, the pH dropped from 7.0 to 6.4.**

Experimental Conclusions

- The degassed distilled water control demonstrates how easily water absorbs $CO_{2.}$ This is true for both fresh and salt water. In the case of our freshwater control, the pH dropped from 7.0 to 6.4.
- **Unbuffered distilled water exposed to an excessively high level of CO_2 rapidly turns firmly acidic, with a pH of much less than 6.4.**

Experimental Conclusions

- The degassed distilled water control demonstrates how easily water absorbs CO_2. This is true for both fresh and salt water. In the case of our freshwater control, the pH dropped from 7.0 to 6.4.
- Unbuffered distilled water exposed to an excessively high level of CO_2 rapidly turns firmly acidic, with a pH of much less than 6.4.
- **Buffered simulated sea water, under an atmosphere containing over 10 times the CO_2 of today's air, declines to a pH of about 7.4, but remains firmly basic.**

Experimental Conclusions

- The degassed distilled water control demonstrates how easily water absorbs CO_2. This is true for both fresh and salt water. In the case of our freshwater control, the pH dropped from 7.0 to 6.4.
- Unbuffered distilled water exposed to an excessively high level of C CO_2 O2 rapidly turns firmly acidic, with a pH of much less than 6.4.
- Buffered simulated sea water, under an atmosphere containing over 10 times the CO_2 of today's air, declines to a pH of about 7.4, but remains firmly basic.
- **The buffered sea water control pH doesn't change, indicating that absorption of ambient CO_2 from the air doesn't change its pH as it does in fresh water**

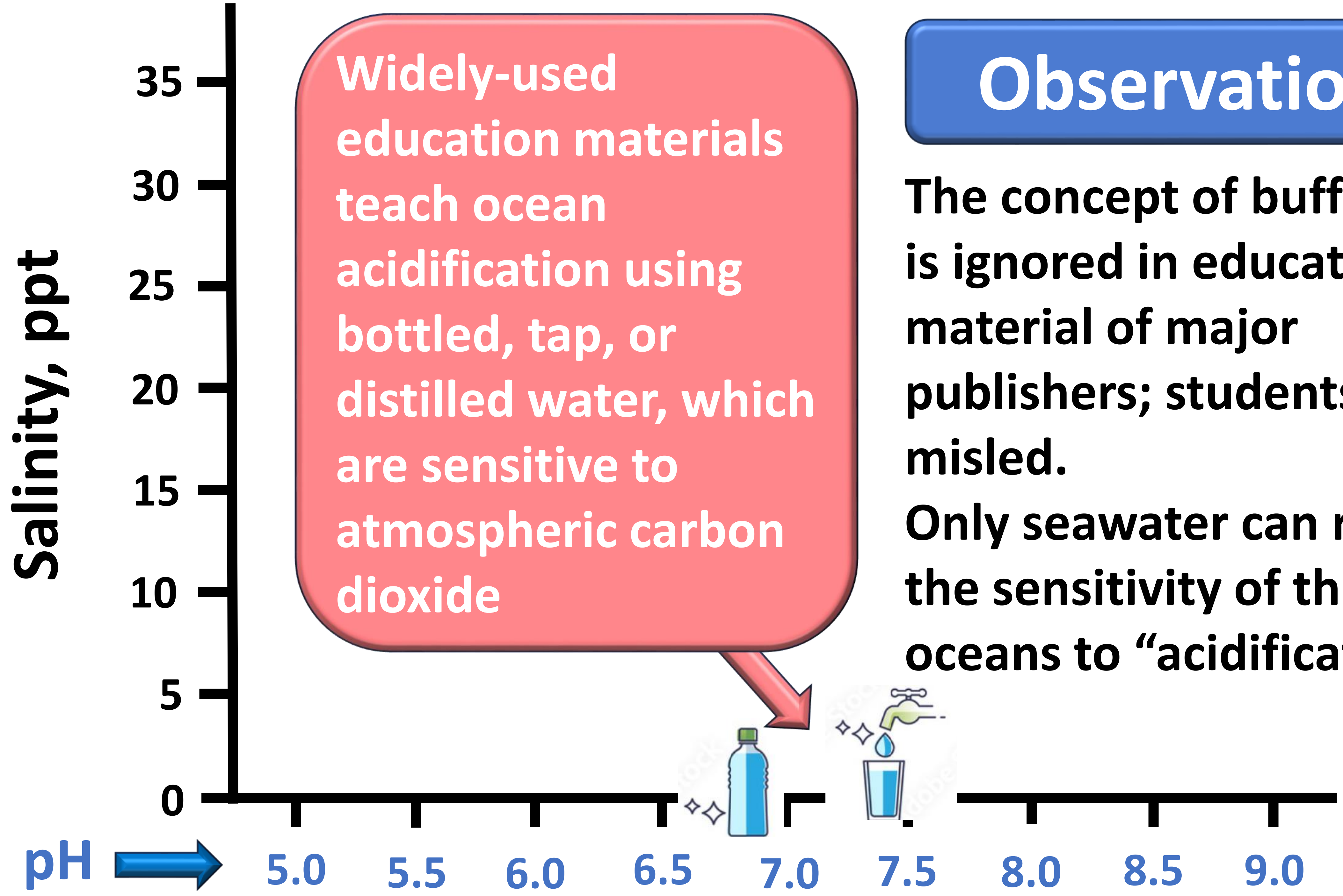
Experimental Conclusions

- The degassed distilled water control demonstrates how easily water absorbs CO_2. This is true for both fresh and salt water. In the case of our freshwater control, the pH dropped from 7.0 to 6.4.
- Unbuffered distilled water exposed to an excessively high level of CO_2 rapidly turns firmly acid, with a pH of much less than 6.4.
- Buffered simulated sea water, under an atmosphere containing over 10 times the CO_2 of today's air, declines to a pH of about 7.4, but remains firmly basic.
- The buffered sea water control pH doesn't change, indicating that absorption of ambient CO_2 from the air doesn't change its pH as it does in fresh water
- **The level of CO_2 in this experiment is unrealistically high and doesn't reflect reasonable or probable increases in the world's ambient CO_2. It does, however, demonstrate the strong resistance of a buffered solution to a change in pH.**

Conclusions

Buffering Matters

Our CO_2 emissions are not endangering sea life



Observation

The concept of buffering is ignored in education material of major publishers; students are misled.

Only seawater can reflect the sensitivity of the oceans to “acidification.”

Observation

Experimental protocol that does not measure the level of CO_2 avoids the impact of the >5,000 ppm CO_2 level generated by antacid tablets. This level is about 2½ times the atmospheric CO_2 content when precursors to today's corals and other hard-shelled marine life evolved.

Ocean Health – Is there an "Acidification" problem?

[Ocean Health White Paper REV 061120.indd (co2coalition.org)](co2coalition.org)