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### Acidic Properties of CO<sub>2</sub> in Aqueous Solutions



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#### Abstract

A series of 2000 mL graduated cylinders are filled with colored solutions and several small pieces of solid dry ice (CO<sub>2</sub>) are gently added to the cylinders. Almost immediately the colors of the liquids begin to change, some slowly over a period of a few minutes, others more quickly, and some exhibiting several color changes one after the other.

## Materials

Solid Dry Ice	Dry Ice Container
6- 2000 mL graduated cylinders	scooper for dry ice
6- 1 L plastic storage bottles	Universal Indicator
Bromothymol blue	Phenolphthalein
Ethanol	3',3"-dibromothymolsulfonephthalein
Sodium Hydroxide Solution	6 – 100 mL stock bottles
Insulated Gloves	

## Safety

Solid dry ice sublimates at  $-78^{\circ}\text{C}$ . Contact with the bare skin causes frostbite. Always use insulated gloves and wear safety goggles when handling it. Special care should be taken in handling the indicators, which could be potentially very hazardous if ingested, and cause irritation if they contact the skin or are inhaled. Sodium hydroxide solution can cause burns and is also irritating to the skin, eyes and respiratory tract. Always work in a vented hood space and wear gloves and safety goggles when working with these materials.

## Procedure

Preparation of Stock Solutions:

Phenolphthalein indicator solution—prepare 100 mL of stock solution, dissolve 0.05g of phenolphthalein in 50 mL of ethanol and dilute the resulting solution to 100 mL with distilled water.

Universal indicator solution—prepare 100 mL of stock solution, dissolve 0.0025 g thymol blue, 0.006 g methyl red, 0.030 g bromothymol blue, and 0.05 g phenolphthalein in 50 mL of ethanol and dilute the resulting solution to 100 mL with distilled water. You could also purchase directly from Sigma Aldrich as was done in this experiment: Product Number : 36828 Brand : Fluka Supplier : Sigma-Aldrich

Bromothymol blue indicator solution—prepare 100 mL of stock solution, dissolve 0.04g of 3',3"-dibromothymolsulfonephthalein in 6.4 mL of 0.01M sodium hydroxide and dilute the resulting solution to 100 mL with distilled water.

0.01M aqueous sodium hydroxide solution—prepare 1 Liter stock solution, mass out 0.40g of NaOH and dissolve in 500 mL of distilled water, and dilute the resulting mixture to 1.0 L with distilled water.

0.1M aqueous sodium hydroxide solution—prepare 1 Liter stock solution, mass out 4.0g of NaOH and dissolve in 500 mL of distilled water, and dilute the resulting mixture to 1.0 L with distilled water.

Preparation of Cylinder Stock Solutions:

Phenolphthalein indicator solution: Add 10.0 mL of the above stock solution to 500 mL of distilled water. Add 15 mL of 0.1M NaOH to produce a basic pH with a nice color. Dilute the resulting solution to 1 Liter with distilled water. When ready pour the entire 1L solution into one of the cylinders and fill to the 1600 mL mark with distilled water. (Two identical solutions were prepared for this experiment).

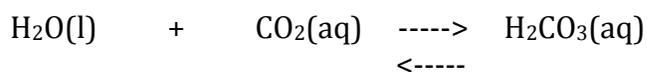
Bromothymol blue indicator solution: Add 10.0 mL of the above stock solution to 500 mL of distilled water. Add 15.0 mL of 0.1M NaOH to produce a basic pH with a blue color. Dilute the resulting solution to 1 Liter with distilled water. When ready pour the entire 1 L solution into one of the cylinders and fill to the 1600 mL mark with distilled water. (Two identical solutions were prepared for this experiment)

Fluka Universal Indicator solution: Add 10 mL of the above universal indicator stock solution to 500 mL of distilled water. Add 15 mL of 0.1M NaOH to produce a basic pH with a light purple color. Dilute the resulting solution to 1 Liter with distilled water. When ready pour the entire 1 L solution into one of the cylinders and fill to the 1600 mL mark with distilled water. (Two identical solutions were prepared for this experiment)

Line all the 2000 mL graduated cylinders up on the counter and add a scoop of solid CO<sub>2</sub> to each and observe the color changes.

## Discussion

When CO<sub>2</sub>(s) is placed into solution we can see the bubbles from the production of CO<sub>2</sub>(g) during the sublimation process. The dissolved CO<sub>2</sub>(aq) reacts with water to produce carbonic acid H<sub>2</sub>CO<sub>3</sub>(aq). The following equilibrium results:



The production of carbonic acid from CO<sub>2</sub>(aq) and H<sub>2</sub>O(l) is an equilibrium, which lies heavily to the left. In other words, the CO<sub>2</sub> in solution exists primarily as CO<sub>2</sub>(aq) with a small amount of carbonic acid forming. The exact ratio at 25 °C has been

estimated to be around 600:1 (Trotman-Dickenson). Enough carbonic acid is formed to effectively change the pH from basic to acidic, affecting the dramatic color changes we see in the cylinders.

Prior to finishing the preparation of the cylinder stock solutions we add 0.1M NaOH to all of the solutions to allow the pH of the solutions to become basic. When sodium hydroxide (NaOH) is dissolved in water it produces sodium and hydroxide ions:



The indicators used undergo color changes at the pH values listed below:

Indicator	Color Change	pH range
Phenolphthalein	Colorless to fuchsia	8.3 to 10.0
Bromothymol blue	Yellow to blue	6.0 to 7.6
Universal Indicator	Red to Violet	0 to 14

The color chart for Universal Indicator shows colors at pH values 1 to 14:

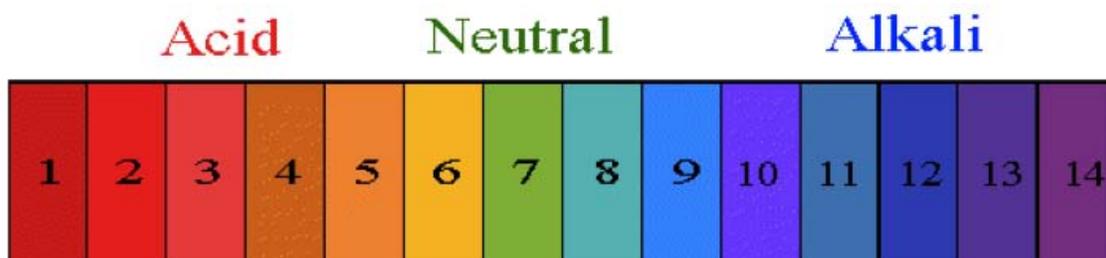


Illustration courtesy of [gcsescience.com](http://gcsescience.com).

The colors in the Universal Indicator result from combinations of the indicator solutions that are mixed together. This is quite complex and covers a range of pH values. Upon adding the solid dry ice, the Universal indicator solution exhibits several color changes one after the other. It starts out purple then changes blue-green, green, yellow, and finally orange-red. Overall this is a good demonstration, which allows us to see the CO<sub>2</sub>(g) in solution that we can't see in the air. We see it as bubbles from the sublimation of CO<sub>2</sub>(s).

## Disposal

The solutions can be discarded by flushing down the drain with large amounts of water. Solid CO<sub>2</sub> can be left to sublime in the hood or used to cool the traps in the laboratory rotary evaporators.

### References

Shakhashiri, B. Z. *Chemical Demonstrations: A Handbook for Teachers of Chemistry*; University of Wisconsin: Madison, WI, **1985**; Vol. 2, pp. 114-120

A. F. Trotman-Dickenson, Executive Ed., *Comprehensive Inorganic Chemistry*, Vol. 1, p. 1232, Pergamon Press: Oxford (1973).

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