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# Demonstrating $CO_2$ Sequestration Using Olivine and Carbonated Beverages with Secondary School Students To Investigate pH and Electrical Conductivity Concepts

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**ABSTRACT:** The introduction of recent science discourses around real-world issues into the classroom is challenging for chemistry educators. Carbon sequestration is one potential topic in this respect. On the basis of a demonstration experiment, it is suggested here to use the silicate mineral olivine as a way to introduce the concept of $CO_2$ sequestration. This real-world topic can be used to introduce standard chemistry topics taught in secondary school, such as pH and electrical conductivity. Moreover, students are challenged to employ these concepts and reaction schemes in analyzing the removal of $CO_2$ by olivine.

**KEYWORDS:** *High School/Introductory Chemistry, Curriculum, Conductivity, Acids/Bases, Demonstrations, Inquiry-Based/Discovery Learning, Aqueous Solution Chemistry, Inorganic Chemistry, Geochemistry, Mathematics/Symbolic Mathematics*

## ■ INTRODUCTION

For several decades, the rationale of curricula at secondary schools has been subject to changes hereby aiming for relevance in society.[1] In this respect, the impact of chemicals and chemical processes upon both the environment and climate change frequently dominates socio-political discussions. An additional challenge in curriculum design has been the introduction of recent scientific discourses in the classroom in order to improve the motivation of students and the relevance of chemistry classes. Therefore, we have designed a novel demonstration experiment that accounts for real-world issues, recent scientific interests, and the incorporation of basic chemical concepts.

Owing to the anthropogenic burning of fossil feedstocks, extra $CO_2$ is released into the Earth's atmosphere in addition to the release of $CO_2$ due to natural processes. This contributes, more or less, to widely known global warming and ocean acidification. Therefore, several scientific solutions have been proposed to prevent or reduce $CO_2$ emissions. One way or the other, this topic has obtained considerable attention from an educational perspective in this *Journal*. For instance, Hammond et al.[2] describe a project for undergraduate students that concerns the fixation of $CO_2$ as part of the RuBisCO enzymatic reaction in photosynthesis, hereby employing concepts and skills, such as gas chromatography and mass spectrometry. Stout[3] also focuses on undergraduate students, although this report is based on open-inquiry approaches. He advocates the importance of incorporating "real-world issues" in laboratory projects, but does not provide experimental descriptions of his $CO_2$ projects. Unlike Stout and Hammond et al., Bozlee et al.[4] use a comprehensive mathematical approach in their analysis and description of $CO_2$ equilibria in seawater and the dissolution of $CaCO_3$. The latter is a major compound in, for instance, coral reef skeletons. Bozlee et al. support their findings with academic concepts like ionic strength. Most remarkable in this respect is the work of Asherman et al.[5] with their so-called $Coo_LCap$ project. In this project, students have to develop an amine scrubbing plant in order to capture $CO_2$. In order to do this, they use the highly toxic, though basic, monoethanolamine. First, the authors mentioned typically focus on students at university level instead of secondary school level. Second, they have not chosen the opportunities of a safe and cheap silicate mineral that has found its application in coastal environments in order to capture atmospheric $CO_2$: olivine. In this demonstration, we attempt to fill both of these gaps.

Recent scientific work increasingly outlines that olivine, with its basic orthosilicate ion, can be used to capture $CO_2$. This leads to carbonation or dissolution of the mineral itself in order to combat ocean acidification.[6] Traditionally, the latter process is described in aqueous solutions as follows, where $x$ denotes the fraction of iron cations relative to the magnesium cations ($0 \leq x \leq 1$):[7−9]

$$Mg_{2(1-x)}Fe_{2x}SiO_4 + 4CO_2 + 4H_2O \rightarrow 2(1-x)Mg^{2+} + 2xFe^{2+} + H_4SiO_4 + 4HCO_3^- \quad (1)$$

As witnessed by eq 1, with the dissolution of olivine, ions are released into the solution and the $[CO_2]$ decreases. This in

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turn touches on secondary school chemistry concepts, such as pH and electrical conductivity ($\sigma$) of aqueous solutions. Therefore, both of these concepts are used in our experimental setup and conclusions.

## ■ MATERIALS

Olivine was purchased from GreenSand (Enkhuizen, The Netherlands), and the carbonated mineral water beverage, Quellbrunn, was from a local grocer. According to the manufacturer of Quellbrunn, the mineral composition of this beverage is $Ca^{2+}$ (70.9 mg/L), $Cl^-$ (14 mg/L), $K^+$ (2.3 mg/L), $Mg^{2+}$ (13.6 mg/L), $Na^+$ (7.3 mg/L), $NO_3^-$ (<0.3 mg/L), $NO_2^-$ (<0.005 mg/L), $SO_4^{2-}$ (41 mg/L), and $HCO_3^-$ (240 mg/L). A Vernier Labquest 2 data logger is used for the measurements that were conducted with a pH electrode and conductivity electrode (both from Vernier). MN 615 filters were used.

## ■ PROCEDURE

All measurements were conducted at room temperature with Quellbrunn as the source of $CO_2$. Before the experiments, the pH electrode was calibrated by measuring two buffer solutions with pH 4.00 and 9.00, respectively. The conductivity electrode was calibrated with a standard NaCl solution of 1,000 $\mu$S/cm. Figure 1 shows the demonstration apparatus that is used in five different measurements series (see Supporting Information). These series differ in the number of filters filled with 30 g of olivine considered from top to bottom, which is 0, 1, 2, 3, and 4. Each experiment was conducted three times with 250 mL of freshly opened soda (pH = 5.1; $\sigma$ = 415 $\mu$S/cm) and took about 15 min. The funnels, with a filter therein, are separated from each other with a fixed distance. Subsequently, the pH and $\sigma$ are measured from the filtrate. Both pH and $\sigma$ are averaged, and the distribution of the resulting values is quantified with the standard deviation.

## ■ HAZARDS

Both olivine and the carbonated beverage are safe to handle, as olivine is unlikely to be swallowed or inhaled in this experiment, but it is still imperative to wear appropriate clothing and goggles.

## ■ RESULTS AND DISCUSSION

Standard linear regression was done in Excel, and as shown in Figure 2, this yields good fits for both pH ($R^2$ = 0.9124) and $\sigma$ ($R^2$ = 0.9997). In this demonstration experiment, both quantities depend on each other. That is, increasing the number of olivine filters is followed by an increase in pH and $\sigma$ as compared to the values for freshly opened soda. Owing to olivine, $[CO_2]$ decreases. Hence, the solution becomes less acidic, and the pH increases. Using eq 1, the dissolution of olivine in the presence of $CO_2$ comes with an increase in concentration of free ions, for example, $Mg^{2+}$ and $Fe^{2+}$, and thus $\sigma$ increases too.

In addition, this demonstration experiment can be easily extended to open-inquiry approaches as the chemicals used are safe to handle.[3]

Following Linn and Eylon,[10] the experimental results provide food for thought in a classroom discussion at secondary school level. For instance, the pouring out of the carbonated beverage during the experiment reveals gas bubbling. Thus, gaseous $CO_2$ is directly released into the

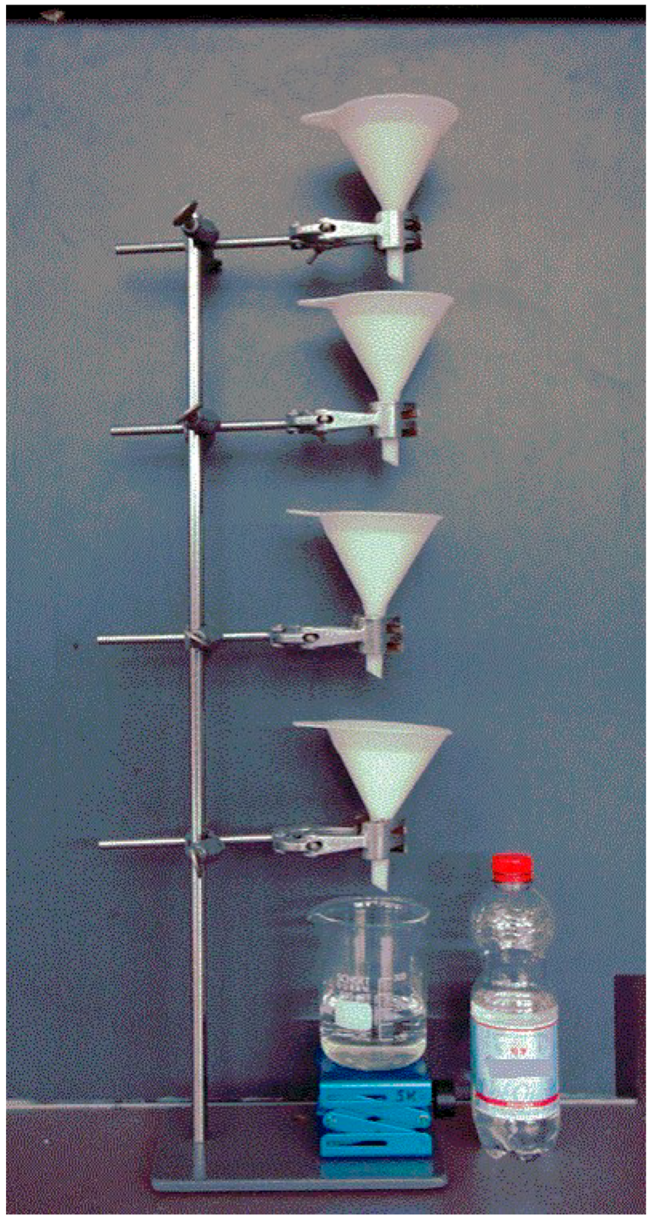

**Figure 1.** Demonstration apparatus with four filters.

atmosphere. Consequently, a critical student might apply the following schemes:[4]

$$CO_2(g) \rightleftharpoons CO_2(aq) \quad (2)$$

$$CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq) \quad (3)$$

$$H_2CO_3(aq) + H_2O(l) \rightleftharpoons HCO_3^-(aq) + H_3O^+(aq) \quad (4)$$

$$HCO_3^-(aq) + H_2O(l) \rightleftharpoons CO_3^{2-}(aq) + H_3O^+(aq) \quad (5)$$

With the release of gaseous $CO_2$, all of the above equilibria shift to the left, and therefore, $[H_3O^+]$ decreases. Consequently, the pH increases, though this conclusion is at odds with the $\sigma$ measurements. Indeed, eq 4 shows that if $[H_3O^+]$ and $[HCO_3^-]$ decrease, then the total concentration of free ions decreases too. This should give a significant lowering of $\sigma$. As witnessed in Figure 2, the opposite is observed. Apparently, the basic orthosilicate ion is at work here, because it reacts with free acids, for example, $H_2CO_3$, which is followed by the



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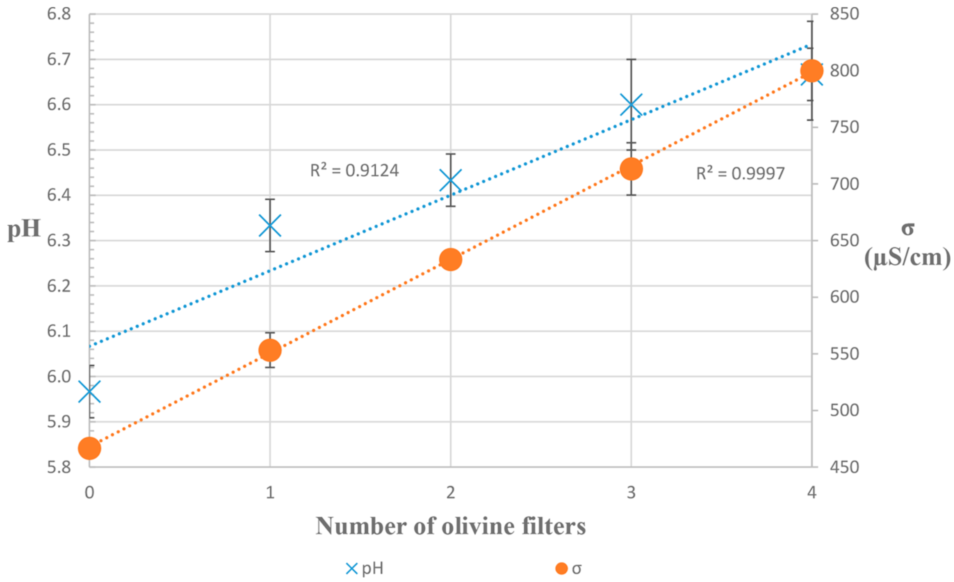


**Figure 2.** Number of olivine filters versus pH (left axis) and $\sigma$ (right axis).

dissolution of olivine and an increase in $\sigma$. This is in line with the filtrate that results from four filled filters. In contrast with freshly opened soda, this filtrate is visually free from gas bubbling; that is, no atmospheric release of $CO_2$ is observed (see Supporting Information for detailed observations).

## CONCLUSION

On the basis of this safe and low-cost experiment and in the spirit of a real-world issue, secondary school students can be challenged to improve their scientific skills of combining different chemical quantities that describe the same phenomenon.

## ASSOCIATED CONTENT

### Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.7b00680.

Additional photographs of olivine and carbonated beverage (PDF)

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### Notes

The authors declare no competing financial interest.

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