
1. What is the motivation that the researchers present at the beginning of the article to study the reaction of $\text{CaCO}_3$ with acid?

2. List the chemical reactions that occur in the atmosphere to create acid rain from the process described in the article. You can choose one acidification process from each of the following: carbon monoxide and nitrogen, sulfur and nitrogen, or sulfur and oxygen. Explain.

3. Based on the data presented in the article, determine whether reaction 1 is a first-order reaction.

$$\text{CaCO}_3(s) + 2\text{H}^+(aq) \rightarrow \text{Ca}^{2+}(aq) + \text{CO}_2(g) + \text{H}_2\text{O}(l)$$

4. Datalogger - When the recorded information depends on time, it is an electronic device that records information along a timeline, such as a pH meter, etc.

(a) What is the advantage of the experimental method presented in the article? Are they suggesting other alternative methods?

(b) Explain the concept Datalogger in the context of the experiment described in the article.

(c) Can you think of other reactions in which one of the reactants is a solid phase that you believe can be investigated in the same way?

5. What are the objectives of the experiment? The researchers define two objectives at the end of the introduction.

(a) Explain what this is and how it is implemented in the article.

(b) Explain the idea of using this method for determining partial reaction rates.

(c) Check if the experiments were conducted under conditions suitable for this method. Refer to the experimental procedure.

(d) What does $k$ represent, according to the equation presented in the article?

6. Translate the text to the original language.

7. "Keto" is an abbreviation for (2) the formation of a double bond of the same elements (Jordan and Jordan). Explain the meaning of "molecule" in this context.

8. Is it necessary to use the instrumentation described in the article as a method of determining the rate of reaction? Justify your answer.
השאלה 8: חלצו את קבוע הקצב האפקטיבי מגרף מס’ 3 והשוי לערך. (אין צורך למצע, הפעולה מספקת выбор עקומת הת政府采购 של \( y \) לכמות התחילית של \( CaCO_3 \) \( x \)? בגרף 9.

(א) הסבירו כיצד קבעו החוקרים את האחוז המשקלי של \( CaCO_3 \) בביצים שבאו משוק המקומי.

(ב) מה ניסוח ההנחה של החוקרים לגבי\\( CaCO_3 \)? מהן מקובלות זו לזו לדעתכם.

A small cap containing 1.5 mL of 1.0-2.0 M hydrochloric acid …

(ג) מהו האחוז המשקלי של \( CaCO_3 \) בביצה זו?

(ד) מהו האחוז המשקלי של \( CaCO_3 \) בביצה זו?

(ה) מהן מסקנות המאמר?

(ב) عمل של המחקרesty הספקים במאמר בחלק 결נה סיווג (חזרה של \( CaCO_3 \) בביצה). בטון \( 27 \) kPa, (and Discussion)

(ו) מנו קשרים עם האחת המשקלי של \( CaCO_3 \) בביצה זו?

(ז) מהן מקובלות זו לזו לדעתכם?

10. חלצו את קבוע הקצב האפקטיבי מגרף מס’ 3 (מספיק לפי הגרף במענה \( CaCO_3 \) והוור \( CaCO_3 \).)

11. מהו האחוז המשקלי של \( CaCO_3 \) בביצה שבאו משוק המקומי?

12. מהן מקובלות זו לזו?

(ב) מה ניסוח ההנחת של החוקרים לגבי \( CaCO_3 \)? מהן מקובלות זו לזו לדעתכם.

13. מенко את תוצאות ליערוי או Latter in yapsemi ו/ו צריכות בנויה על התוצאות המדויקות.
The Earth’s crust consists of about 3.4% (by mass) calcium. Calcium exists primarily as calcium carbonate, calcite, chalk, and marble on Earth or in the ocean (1–4). Acid rain has become a serious environmental problem in most industrial countries as it can destroy buildings, monuments, and statues with high calcium carbonate content. Acid rain is caused by emissions of sulfur dioxide from coal- and oil-burning power plants and of nitrogen oxides from automobiles. In the atmosphere, these emissions are chemically converted into sulfuric acid and nitric acid that accumulate in cloud droplets and fall as precipitation, for example rain or snow. Acid rain has a corrosive effect on limestone and marble as calcium carbonate reacts readily with acids (5):

$$\text{CaCO}_3(s) + 2\text{H}^+(aq) \rightarrow \text{Ca}^{2+}(aq) + \text{CO}_2(g) + \text{H}_2\text{O}(l)$$ (1)

The study of acids on calcium carbonate is frequently taught in basic chemistry courses. Equation 1 can be applied to determine inorganic carbon in rocks and soils when carbonate is converted into carbon dioxide. Unfortunately, these experiments often require expensive equipment, such as a Fourier transform infrared spectrophotometer (6, 7), which is not commonly available in secondary schools. Reaction kinetics are often taught in secondary school or introductory college levels (8). Experiments demonstrating first-order kinetics have been discussed in the literature (9–12). Equation 1 can be used to teach first-order reaction kinetics if acid is present in excess and the rate of liberation of carbon dioxide is monitored.

The application of a datalogger (a computer interfaced to one or more sensors) in biology, chemistry, and physics laboratories in Hong Kong secondary schools is becoming popular. The major advantage of a datalogger is that students can simultaneously monitor, in real time, various parameters of an environment, such as temperature, electric current, electric potential, pressure, photons, pH, and oxygen. Roser and McCluskey have successfully demonstrated the use of a pressure sensor to study the stoichiometry of the reaction of hydrogen carbonate or carbonate with hydrochloric acid (13).

This article describes the application of a Pasco CI-6532 pressure sensor used in conjunction with a datalogger (Figure 1) to monitor the liberation of carbon dioxide in eq 1. The proposed method is simple, safe, and convenient to use. It not only serves for the determination of the chemical kinetics of eq 1 but also can be extended to obtain quantitatively the concentration of calcium carbonate in eggshells.

**Principles**

Equation 1 is first order with respect to calcium carbonate and acid, respectively. If acid is present in large excess, only a small quantity of acid will be used up in the reaction. The concentration of acid is practically constant, and the reaction rate will depend on the concentration of calcium carbonate alone. The reaction, thus, is pseudo-first-order with respect to the concentration of calcium carbonate,

$$\text{rate} = \frac{d[\text{CaCO}_3]}{dt} = -k[\text{CaCO}_3]$$

where $[\text{CaCO}_3]_t$ is the concentration of calcium carbonate at time $t$, and $k$ is the rate constant. The integrated from this equation is,

$$kt = \ln[\text{CaCO}_3]_0 - \ln[\text{CaCO}_3]_t$$

where $[\text{CaCO}_3]_0$ is the initial concentration of calcium carbonate, which is proportional to the final pressure ($P_f$) of CO$_2$ produced. The concentration of [CaCO$_3$], at time $t$ is equal to [CaCO$_3$]$_0$ minus the concentration of CaCO$_3$ reacted. Since the quantity of carbon dioxide liberated is re-

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**Figure 1.** The experimental setup for the determination of calcium carbonate in eggshells.
lated to the concentration of calcium carbonate consumed, eq 3 can be rewritten as,

\[
kt = \ln P_f - \ln (P_f - P_{CO_2})
\]  

(4)

where \(P_{CO_2}\) is the pressure at time \(t\) of carbon dioxide generated. As \([CaCO_3]_0\) and \([CaCO_3]_t\) are proportional to \(P_f\) and \((P_f - P_{CO_2})\) values, respectively, plotting \(\ln(P_f - P_{CO_2})\) against \(t\) will produce a straight line with the slope equal to \(-k\) and \(y\) intercept equal to \(\ln P_f\).

**Experimental Procedure**

The experimental setup is displayed in Figure 1. A known quantity (0.01–0.05 g) of calcium carbonate\(^1\) was placed in a 25-mL suction flask. A small cap containing 1.5 mL of 1.0–2.0 M hydrochloric acid\(^2\) was carefully positioned in the same flask. After the flask had been closed with a rubber stopper and connected to a pressure sensor in conjunction with a datalogger system,\(^3\) the flask was then shaken to mix the calcium carbonate with hydrochloric acid. The carbon dioxide liberated increased the pressure inside the flask, which was monitored at a rate of 10 samples per second and processed by a ScienceWorkshop 500 interface\(^3\) consisting of a datalogger, serial cables, a power supply, and control software. The data were logged in a notebook PC for real-time display as shown in Figure 2.

**Hazards**

Hydrochloric acid is corrosive to skin and eyes. Inhalation of vapor may cause irritation of nasal and respiratory tract. Ingestion causes gastrointestinal tract discomfort, nausea, and vomiting. Students must wear splash goggles and gloves to prevent contact with acid.

As the pressure buildup in the suction flask may be large during the experiment, the rubber stopper should be tightly closed and the tubing connected to the suction flask and pressure sensor should be tightly fastened to prevent any gas and acid fume leakage. Caution should also be taken when releasing pressure buildup in the suction flask at the end of each experiment so that acid fumes are not inhaled by the students.

**Results and Discussion**

Using the results obtained in Figure 2, linear curves were plotted and displayed in Figure 3. The rate constant was determined to be 0.068 ± 0.011 s\(^{-1}\) \((n = 5)\). The results obtained from Figure 2 can also be used to construct a calibration curve for calcium carbonate by plotting the quantity of calcium carbonate used against the change of pressure in the suction flask (Figure 4). As expected the larger the quantity of calcium carbonate used, the greater change in pressure was recorded.

The calcium carbonate content in eggshells from a local market was determined from the calibration curve (Figure 4). A raw eggshell was ground into fine granules. About 0.05 g of eggshell was transferred to the suction flask and mixed with hydrochloric acid. The pressure generated was recorded by the pressure sensor and the datalogger. The pressure change

<table>
<thead>
<tr>
<th>Sample</th>
<th>[CaCO(_3)] in eggshell (% w/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egg</td>
<td>83.4 ± 3.3</td>
</tr>
<tr>
<td>Salted egg</td>
<td>83.7 ± 3.0</td>
</tr>
<tr>
<td>Quail egg</td>
<td>85.6 ± 2.0</td>
</tr>
</tbody>
</table>

*Note: The [CaCO\(_3\)] is the average value of five determinations.*

Figure 2. Real-time monitoring the CO\(_2\) pressure when CaCO\(_3\) reacts with excess HCl.

Figure 3. Linear plots at various quantities of CaCO\(_3\). \(\ln(P_f - P_{CO_2})\) against \(t\): (1) 0.01; (2) 0.02; (3) 0.03; (4) 0.04, and (5) 0.05 g CaCO\(_3\) were used.

Figure 4. Calibration plot of pressure change in the suction flask versus the quantity of calcium carbonate.
in the suction flask due to the eggshell sample was compared with the calcium carbonate calibration curve shown in Figure 4. The calcium carbonate content in various eggshells was determined, and the results are displayed in Table 1. The calcium carbonate content was found to be 80–85% (w/w). Thus, it is the main component in eggshells. Similarly, this method can also be applied to determine the calcium carbonate in chalk.

**Conclusion**

The application of a datalogger and a pressure sensor provides a convenient method to determine the calcium carbonate content in some samples as well as to study the chemical kinetics of eq 1. Moreover, it is possible to modify this experiment to demonstrate other reactions associated with the liberation of gases, for example, sulfur dioxide from sodium sulfite and acid.

**Acknowledgment**

The authors would like to express their sincere thanks to Raymond W.-H. Fong of the Curriculum Development Institute of Education Department, Hong Kong, SAR, for the loan of the ScienceWorkshop system and a notebook PC.

**Supplemental Material**

Instructions for the students and notes for the instructor are available in this issue of *JCE Online*.

**Notes**

1. Calcium carbonate was obtained from Acros Organics, Geel, Belgium.
2. Hydrochloric acid was purchased from BDH Laboratory Supplies, Poole, England.
3. The Pasco Model CI-6532 absolute pressure sensor (0–700 kPa) and ScienceWorkshop 500 interface were purchased from Pasco Scientific, Roseville, CA (http://www2.pasco.com, accessed Feb 2004). The total cost is approximately $700 (U.S.).

**Literature Cited**