Lab: Macroscopic Properties of Equilibrium

INTRODUCTION

A closed bottle of orange juice may be kept indefinitely with no loss of the juice. A closed bottle of a soft drink may be kept indefinitely with no loss of fizz! Yet, when the bottle is opens, within a short period of time, the fizz has gone.

Reactions occurring in both open and closed containers appear to stop after a while. What causes the reactions to stop?

In this experiment, you will use the equipment and materials provided to develop a procedure to conduct an experiment to study a reaction occurring in a closed container (soft drink bottle) and then in an open container (graduated cylinder). The reaction is that of carbon dioxide with water.

THEORY

Carbon dioxide is a sparingly soluble gas. At a higher pressure, the gas is more soluble in water- no doubt you have guessed this form the behaviour of $CO_{2\,(g)}$ in carbonated drinks. In the unopened bottle, the pressure is higher than the atmosphere's. This keeps CO_2 in solution. As soon as you open the bottle, the pressure suddenly becomes the same as the atmosphere's, and some CO_2 fizzes out. This can be explained by the following equilibrium, in terms of Le Chatelier's Principle…

$$CO_{2\,(g)} \quad + \quad \text{pressure} \rightleftharpoons CO_{2\,(aq)}$$

An increase in pressure would put a stress this equilibrium. To relieve this stress, in accordance with Le Chatelier's Principle, the equilibrium would shift to the right because this shift would cause the number of gas molecules to decrease and that would lower the pressure. Such a shift, of course, would put more CO_2 into the dissolved state. Conversely, if the pressure were reduced, then the equilibrium would shift to the left, and CO_2 would come out of the solution (and the drink would be flat!).
A small fraction of CO_2 molecules dissolved in water precipitate in the following equilibrium to give a small concentration of carbonic acid, H_2CO_3…

$$CO_{2\,(aq)} \quad + \quad H_2O \rightleftharpoons H_2CO_{3\,(aq)}$$

If, because of higher pressure, there were more CO_2 in solution- more $CO_{2(aq)}$ – then this equilibrium would shift to the right to use up some of this extra CO_2, and more $H_2CO_{3(aq)}$ would form.
Carbonic acid is a weak acid, (partially ionized), so a small percentage of its molecules ionize according to the following equilibrium…

$$H_2CO_{3\,(aq)} \rightleftharpoons H^{+1} \quad + \quad HCO_3^{-1}\,_{(aq)}$$

At 101.3 kPA and 25ºC, the concentration of H^{+1} is about 2×10^{-5} M. However, this number would be greater if the pressure were higher because the concentration of H_2CO_3 would be greater. This is why a higher pressure makes the carbonated drink more acidic!

Acids react with bicarbonates (aka: hydrogen carbonates, HCO_3^{-1}), and carbonates to generate $CO_{2(g)}$ and H_2O, according to the following reactions…

$$H^{+1} + HCO_3^{-1}{}_{(aq)} \rightleftharpoons H_2O + CO_{2(g)}$$

$$2\,H^{+1} + CO_3^{-2}{}_{(aq)} \rightleftharpoons H_2O + CO_{2(g)}$$

But for these reactions to occur , the H^{+1} must come into direct contact with the HCO_3^{-1} or CO_3^{-2} ions. The makers of the well-known analgesic tablets Alka Seltzer take full advantage of this fact. Among the ingredients in these tablets are sodium hydrogen carbonate, and citric acid. Crystals of these substances are able to exist in contact with each other without reacting because the H^{+1} available from the citric acid cannot mingle with the HCO_3^{-1} ions in the sodium hydrogen carbonate. Diffusion in solids is too slow for this to happen. But when the tablets are dropped into a glass of water, the citric acid and sodium hydrogen carbonate dissolve, thus allowing the mixing of the ions and the production of $CO_{2(g)}$ (fizz, fizz!).

Equipment and Materials

You will be provided with…
100 mL graduated cylinder, thermometer, pH paper and solution, balance, stopwatch, one Alka Seltzer tablet, one bottle of colourless soft drink, and any other suitable equipment that your planning requires (just let me know prior to the day of the lab).

Assignment

1. From the Introduction, formulate a problem statement clearly.
2. Explain the hypothesis (prediction) relating to your problem statement.
3. From the Introduction, Theory and Equipment and Materials list, develop a procedure (a diagram is always helpful).
4. From the Procedure:
   a) state the manipulated and responding variables, and
   b) list some controlled variables
5. Prepare an observation table for the collection of both qualitative and quantitative data.

Check your procedure with me before you begin the experiment.

ANALYSIS

1. Consider both the open and closed containers. What reaction(s) are occurring in each container?
2. Consider the reaction in the graduated cylinder (open system). What evidence led you to decide when the reaction(s) had stopped.
3. a) Explain why the reaction(s) in the graduated cylinder stopped.
   b) Consider the same reaction occurring in the closed soft drink bottle (closed system). Is there evidence that suggests that the reaction has stopped?
4. Did the reaction in the closed bottle stop? Explain.

You will be tested for Planning (a), Planning (b) and Data Evaluation.