ONE-DIMENSIONAL SYSTEMS: Titration

This experiment is a continuation of our study of one-dimensional systems. All of these systems are governed by an equation of the form $x = f(x)$, where $x$ is the dynamical variable. For this experiment $x$ is the pH of a chemical solution.

**Objectives:**
1. Acquaintance with LoggerPro software
2. Graphical Analysis:
   - description of system behavior from graph
   - identification of fixed points from plot of time dependence
   - identification of fixed points from phase plots
3. Explore the fixed points:
   - dependence on system parameters
   - independence of initial conditions
   - stability of fixed points

As a strong base is gradually added to a sample of strong acid, the pH of the system varies nonlinearly from low pH (acidic) through neutrality and on to high pH (basic). In this experiment, we will examine the variation of pH as a function of volume of base added.

A sample of HCl (the acid) is placed into an erlenmeyer flask. A pH probe, which is connected to the computer, is placed inside the flask. A buret, filled with NaOH (the base), is positioned so that the flow of NaOH into the flask is not obstructed by the probe. A magnetic stirring system is utilized to ensure that mixing is rapid and complete. The data (pH vs. time) from the probe can be displayed graphically on the computer in real time.

The chemical reaction under investigation is typical of acid-base titrations:

$$\text{HCl}^{\text{aq}} + \text{NaOH}^{\text{aq}} \rightarrow \text{NaCl}^{\text{aq}} + \text{H}_2\text{O}^{\text{l}}$$

which simplifies to $\text{H}^+(aq) + \text{OH}^-\text{aq}) \rightarrow \text{H}_2\text{O}^{\text{l}}$

The pH of the system is a measure of the hydrogen ion concentration (where the units are in molarity, or moles/liter):

$$\text{pH} = – \log [\text{H}^+]$$
In an aqueous solution, the hydrogen ion concentration is inexorably linked to the concentration of the hydroxide ion, since their product is always a constant, $K_w$ ($1.0 \times 10^{-14}$ at 25°C).

$$[H^+][OH^-] = K_w$$

**Actions:**
1. Obtain one 25.0 mL buret.
2. Pour about 30 mL of 0.050 M NaOH from the reagent container into a clean beaker; rinse the buret with this solution and fill it according to your instructor's directions.
3. Use a 125 mL beaker for your reaction vessel.
4. Put roughly 20 mL of deionized water into the beaker and pipet 3.0 mL of 0.10 M HCl into the beaker.
5. Set up your beaker with a small stir bar on a stirring motor and turn on the motor.
6. Clamp the buret containing base above the reaction beaker.
7. Clamp your pH probe so that the tip of the plastic probe covering is resting gently on the bottom of the beaker and is not in the way of the stir bar.
8. Select the pH file under Experiment Files on the LoggerPro software on your computer.
9. Once the file is loaded, simultaneously click the mouse on START and open up the buret stopcock completely.
10. Click STOP when the titration curve has "topped off" or when 10 mL of NaOH has been delivered.

**Data Analysis:**
- ♦ print the graph of $pH$ vs. time and attach to report (Plot T1).
- ♦ on a new graph, plot $p\dot{H}$ vs. $pH$, i.e. the phase portrait, and attach to report (Plot T2). On your graph, circle the fixed point and indicate with arrows the direction of the system trajectories on the axis.

**Questions:**
- ♦ Responses for each of the following items should be included in your report.
1. Explain the similarities of Plot T1 to the logistic map as seen in Chapter 2. Are the underlying dynamics likewise similar?
2. How does the rate of addition of base affect Plot T1? Plot T2?
3. Assume that acid were added to base rather than base to acid. Make a qualitative sketch of the corresponding Plots T1 and T2?
4. How does this experiment compare to the cooling and RC circuit experiments? Is it linear? Explain your answer.