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 $\dot{x} = f(x)$, where x is the dynamical variable. For this experiment x is the pH of a chemical solution.

Objectives:

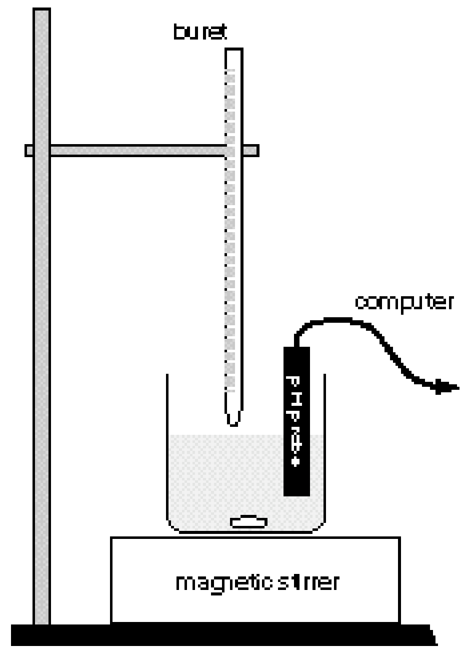
1. Acquaintance with *Logger Pro* software

2. Graphical analysis

- -- description of system behavior from graph
- -- identification of fixed points from time dependence
- -- identification of fixed points from phase plots
- -- classification of the 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 time, as the base is added continuously.

A sample of HCl (the acid) is placed into a beaker. A pH probe, which is connected to the computer, is placed inside the flask. A burette, 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 evolution of the pH as base is added could be described by a rate equation of the form

$$p\dot{H} = f(pH)$$

where *f(pH)* is a complicated function that we do not know. Even though we do not have an explicit form for *f(pH)*, we can still analyze and describe the dynamics of the system using graphical methods.

Actions:

Safety Note: Splash proof goggles and gloves should be worn when working with chemicals.

1. Place the magnetic stir bar in a 150mL beaker. Add 3.0 mL of 0.10 M HCl from the HCl burette into the beaker. Then add roughly 20 mL of deionized water. This will be your reaction vessel.
2. Check that the NaOH burette has at least 15mL of 0.050 M NaOH solution. If not, use a funnel to fill it to this level (as measured from the bottom).
3. Lower the clamped 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.
4. Lower the clamped NaOH burette so that the opening is below the beaker rim.
5. Start the motor on the magnetic stirrer.
6. Open the **Titration** *Logger Pro* file on your computer. The pH reading (displayed at the bottom of the screen) should have a value of roughly 2.
7. Start data collection via the **Collect** button and immediately open up the burette stopcock completely.
8. Click STOP when either the titration curve has leveled off – this should occur at a pH value just above 12.

Data Analysis:

♦ **Print and attach the following plots to your lab report.**

- pH vs. time
- $p\dot{H}$ vs. pH

Questions:

♦ **Include answers to the following questions in your lab report.**

1. On the phase portrait for the above titration, identify any fixed points and classify their stability. Draw the vector field on the horizontal (pH) axis. Remember that the pH must lie in the range [0, 14].
2. Identify similarities and differences between the phase portraits for the above titration and the logistic model (Fig. 2.3.3 in your textbook). Are the underlying dynamics similar? Explain your answer.
3. Imagine adding acid to base rather than base to acid. Sketch the pH vs. time plot and $p\dot{H}$ vs. pH plot that you would expect. For the phase portrait, identify fixed points, classify their stability and draw the vector field on the horizontal (pH) axis.
4. How does this experiment compare to the cooling and RC circuit experiments? Is it linear? Explain your answer.