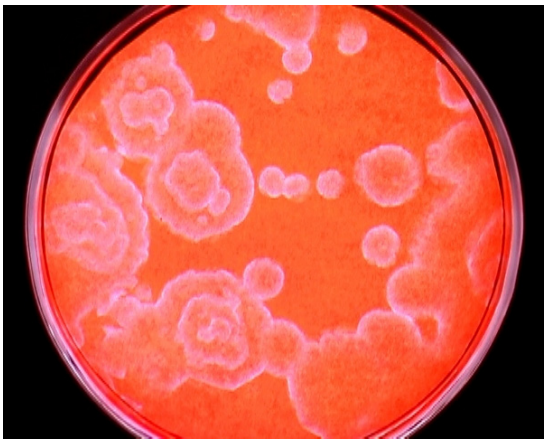
Chemical Waves



Equipment:

two beakers (50 mL)
two beakers (100 mL)
graduated cylinder (100 mL)
volumetric pipet (2 mL)
two volumetric pipets (10 mL)
magnetic stirrer with stir bar
spatula
Petri dish (diameter: 10 cm)
overhead projector and black cardboard

Chemicals:

sodium bromate
concentrated sulfuric acid
malonic acid
sodium bromide
ferroin indicator solution (0.1 wt.%)
deionized water

Safety:

sodium bromate ($NaBrO_3$):

H272, H302, H315, H319, H335
P210, P261, P305 + P351 + P338

concentrated sulfuric acid (H_2SO_4):

H290, H314
P280, P301 + P330 + P331, P303 + P361 + P353, P305 + P351 + P338, P310

malonic acid ($CH_2(CO_2H)_2$):

H302, H318
P273, P305 + P351 + P338

The chemicals cause very severe skin burns and eye damage. Therefore, it is absolutely necessary to wear a lab coat, safety goggles and protective gloves. Because bromine is produced during the preparation, this step should be performed in a fume hood.

Procedure:

Preparation: The following solutions have to be prepared:
Solution A: 2 mL of concentrated sulfuric acid are added to 67 mL of deionized water. Subsequently, 5 g of sodium bromate are dissolved in the acidic solution.
Solution B: 1 g of malonic acid is dissolved in 10 mL of deionized water.
Solution C: 1 g of sodium bromide is dissolved in 10 mL of deionized water.
Under a fume hood, a 100 mL beaker is placed on the magnetic stirrer. 12 mL of solution A are poured into the beaker. Subsequently, 2 mL of solution B and 1 mL of solution C are

added while stirring. After the addition of the last solution, one can observe a yellow brown color caused by the production of bromine. After the solution has cleared, 3 mL of the ferroin indicator solution are added.
Procedure: The solution is gently poured into the Petri dish on the overhead projector so that it just covers the bottom (for better visibility of the effect, it is recommended to cover the free projector area by black cardboard).

Observation:

After a short while, some light blue spots appear in the solution. These spots grow into a series of expanding more or less concentric rings. The colors disappear if the dish is shaken, and then reappear. Eventually, a noticeable gas evolution begins to take place additionally.

Explication:

Oscillating chemical reactions such as the Belousov-Zhabotinsky reaction are reactions that show periodic variations of some of the components in time or space. In cases where one (or more) of the components has a visible color, they are spectacular and suited to stimulate the students´ interest in chemistry. However, the mechanisms of these reactions are very complex. The Belouzov-Zhabotinsky reaction (in short BZ reaction), for example, the reaction between malonic acid and bromate with the overall reaction equation

$$3\ CH_2(CO_2H)_2|w + 4\ BrO_3^-|w \rightarrow 4\ Br^-|w + 9\ CO_2|w + 6\ H_2O|l,$$

is thought to involve around 18 different steps which have been the subject of a number of research papers. But in order to gain a first understanding of this type of reaction, the following strongly simplified reaction scheme can be considered:
The first step should be an autocatalytic process involving the reactant A and an intermediate X:

$$A + X \xrightarrow{k_1} 2\ X\,.$$

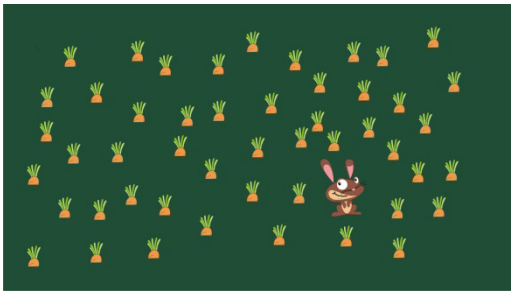
k is a rate coefficient (rate constant). In the second step X reacts with another intermediate Y in a second autocatalytic process:

$$X + Y \xrightarrow{k_2} 2\ Y\,.$$

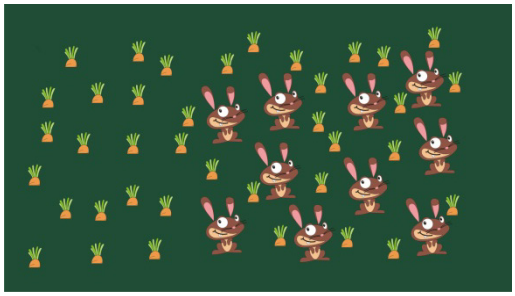
The final step is the conversion of Y to the stable product P:

$$Y \xrightarrow{k_3} P\,.$$

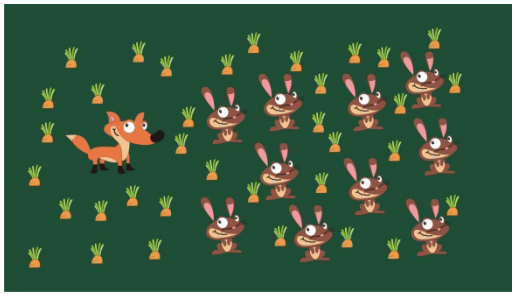
To visualize the situation predator-prey models can be used. Here, A can be carrots, X a population of rabbits, Y a population of foxes and P the foxes that have died.



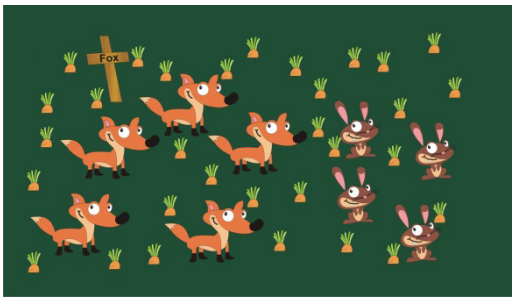
At the beginning, there is a real abundance of carrots.



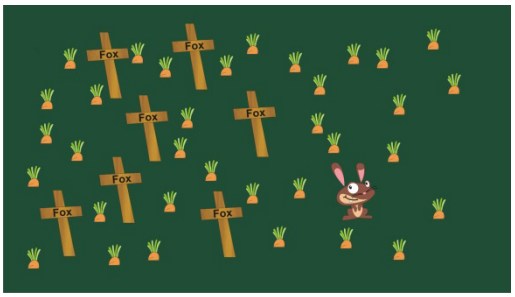
The rabbits live very well on carrots and become plentiful.



This brings the foxes into to arena because they like to eat rabbits.



The number of the foxes starts to grow whereas the rabbit population diminishes.



Eventually, the voracious foxes have eaten nearly all of the rabbits. Famine sets in and the foxes die bringing the system back to the first step.

In the case of the BZ reaction, the reduced (red color) and oxidized states (blue color) of the redox catalyst ferroin are oscillating out of phase such as the rabbit and the fox populations. The cycles repeat as long as the supply of reactant (carrots) holds out.

The coupling between an autocatalytic chemical reaction such as the BZ reaction and diffusion by using an unstirred layer of the reaction mixture can create spatial structures. One can observe the propagation of succeeding concentration fronts, a phenomenon called “chemical waves.”

Disposal:

After the reaction has been completed, the solution is neutralized with sodium hydroxide. The precipitate is separated by sedimentation and decantation and subsequently disposed of as inorganic hazardous waste. The liquid is flushed down the drain with copious amounts of water.

Reference:
http://mysite.science.uottawa.ca/mroger2/BZreaction.html