14. Chemical Oscillators
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Hellenic Physical Society
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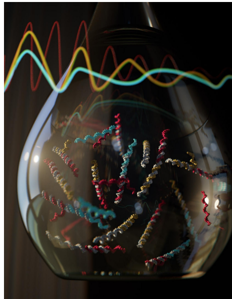
Contents



Problem to be investigated

$$IO_3^- + 2H_2O_2 + CH_2(COOH)_2 + H^+ \rightarrow ICH(COOH)_2 + 2O_2 + 3H_2O$$

Examples of oscillating chemical reactions are the **Briggs-Rauscher** reaction or the **Belousov-Zhabotinsky** reaction which result in periodic color changes. While some of such reactions are difficult to reproduce, there are multiple ways to produce a simpler and more reliable chemical oscillator. Propose a problem about an **interesting** and **simple** chemical oscillator.

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

What do we call Chemical Oscillator ?

A chemical oscillator is a complex mixture of reacting chemical compounds in which the concentration of one or more components exhibits periodic changes.

Both of these systems were heterogeneous and it was believed then, and through much of the last century, that homogeneous oscillating systems were nonexistent.

Theory

In an oscillating system the energy-releasing reaction can follow at least two different pathways, and the reaction periodically switches from one pathway to another. One of these pathways produces a specific intermediate, while another pathway consumes it.

Theory

THE CONCENTRATION OF THIS INTERMEDIATE TRIGGERS THE SWITCHING OF PATHWAYS. WHEN THE CONCENTRATION OF THE INTERMEDIATE IS LOW, THE REACTION FOLLOWS THE PRODUCING PATHWAY, LEADING THEN TO A RELATIVELY HIGH CONCENTRATION OF INTERMEDIATE. WHEN THE CONCENTRATION OF THE INTERMEDIATE IS HIGH, THE REACTION SWITCHES TO THE CONSUMING PATHWAY.

Experimental Procedure

Solution A : I prepared 100 mL of 9% H_2O_2, by diluting 30 mL of 30% H_2O_2 with 70 mL of deionized water.

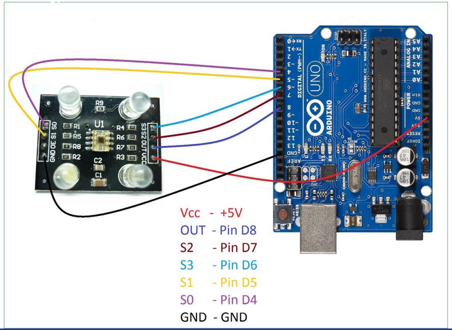
Solution B : I prepared an acidified KIO_3 solution by adding 10 mL of H_2SO_4 to 80 mL of deionized water. 4.3 g KIO_3 dissolved in this solution and diluted to 100 mL.

Solution C : I prepared a starch solution by dissolving 0.1 g of soluble starch in 90 mL of boiling deionized water. When cool, I added 1.5 g malonic acid, 0.4 g $MnSO_4 \cdot H_2O$, stirred and diluted to 100 mL.

Hypothesis & Parameters :

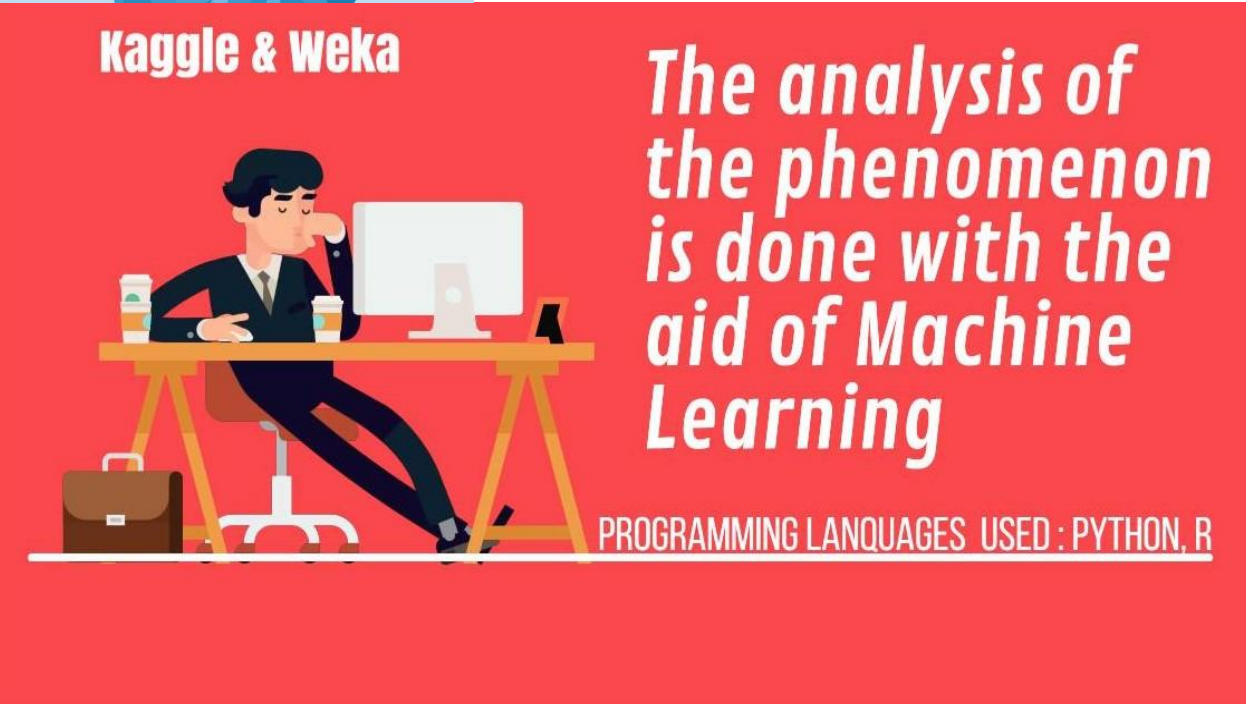
- Higher **Iodine concentration** means a more intense color change.
- Higher **Peroxide concentration** leads to a more time consuming reaction.
- Higher **solution temperature** means a shorter oscillating period.
- Higher concentration of **Malonic Acid** means a longer oscillation.

- Oscillating period is measured with Arduino Gy-31 color sensor :



What happens is that :

When the reaction begins, the solution becomes yellow as I^{1-} (generated from reaction of HOI with H_2O_2, not shown) reacts with HOI under acidic conditions to produce I_2. The solution suddenly changes to dark blue as a buildup of I^{1-} reacts with I_2 in the presence of starch to generate the pentaiodide ion (I_5^{1-}) which is encased in the amylose present in solution. The reaction proceeds by consuming I_2 at a rate greater than it is being produced thus removing the presence of I_5^{1-} and increasing the concentration of I^{1-} (colorless). The oscillations continue until malonic acid or IO_3^{1-} is completely consumed.



It would be very subjective to estimate the concentrations of I_2, I_5 ion and I^{1-} only with a naked eye and in this contest we are all looking for something really **valid** and **scientific**. For this reason, I analysed the video taken from the experiments into photographs. I took the measurements from the arduino color sensor and after the matching of measurements and photos, I was able to by using the **ML program Weka** to make the graphs of color changes in each parameter tested.

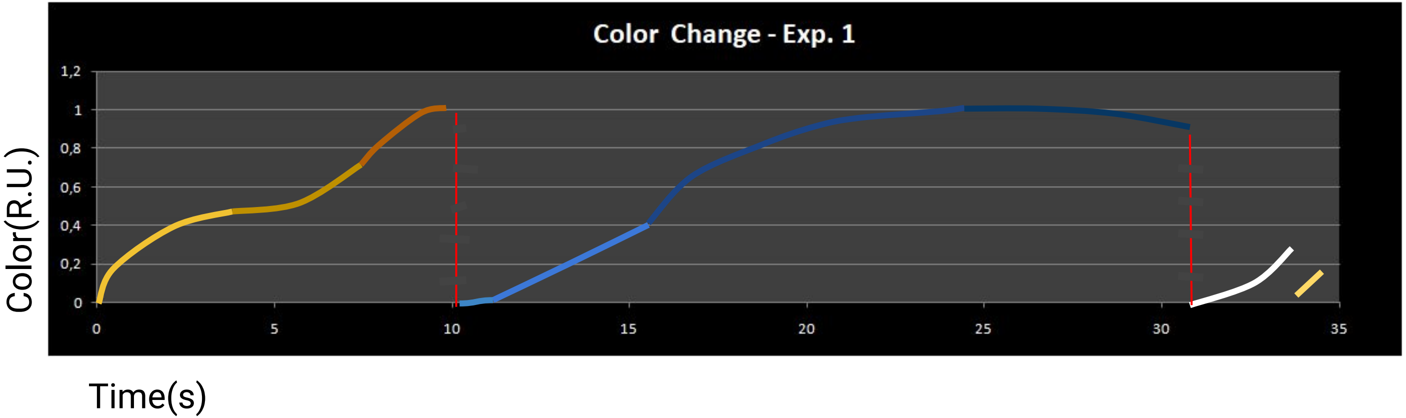
Experimental Procedure 1

Original experiment

Analogies : 1:1:1
Temp. 25℃

Total time of oscillation : 3.12 minutes

Oscillating Period : 34 seconds



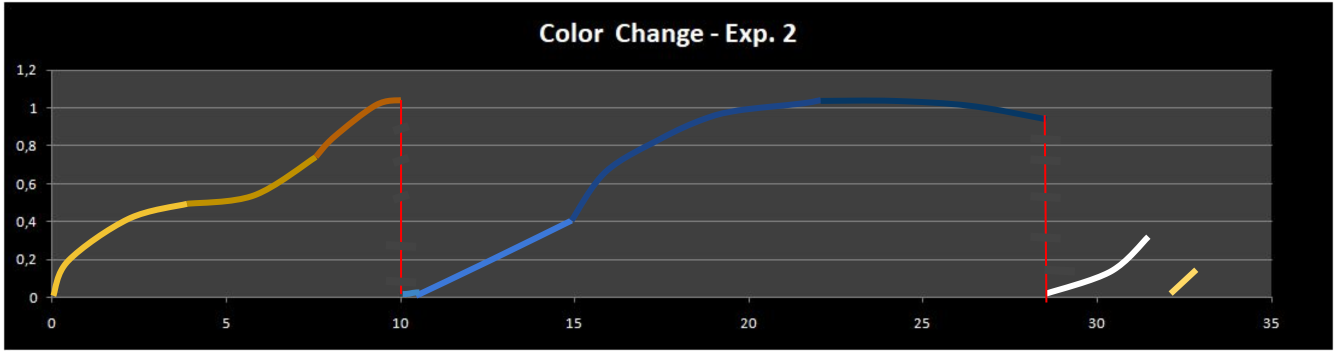
Experimental Procedure 2

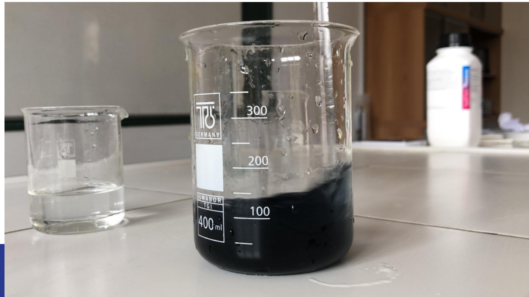
Usage of 50% H_2O_2

Analogies : 1:1:1
Temp. 25℃

Total time of oscillation : 4.02 minutes (+28,8% change from the original)

Oscillating Period : 33 seconds (negligible difference, - 2%)





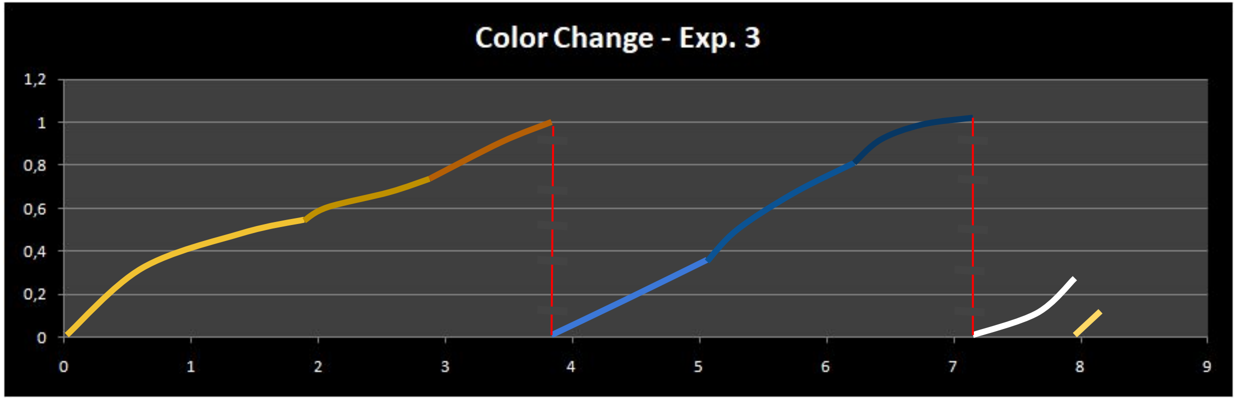
Experimental Procedure 3

Temperature increase : +60%

Analogies : 1:1:1
Temp. 40℃

Total time of oscillation : 23 seconds (-92% change from the original)

Oscillating Period : 8 seconds (-76% change from the original)



Experimental Procedure 4

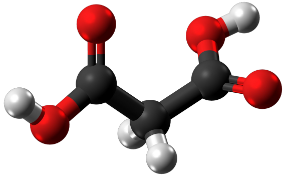
Increase in Iodine concentration

An increase of 20% in KIO_3 (+0.9g) had as a result an increase of 26,5% in the rate of the color change while there is a negligible difference in the total time of the oscillation.

HYPOTHESIS CONFIRMED

Increase in Malonic Acid

An increase of 20% in $C_3H_4O_4$ had as a result an increase of 7% in the total time of the oscillation while the rate of color change remained the same.



HYPOTHESIS CONFIRMED

Conclusions :

In the main reaction the total time is about 3 minutes

With the increase of **Peroxide concentration**, the time of the reaction increases too

Higher **temperature** led to both a shorter oscillating reaction and period of the reaction

Higher concentration of **Malonic Acid** meant a longer oscillation

Higher **Iodine concentration** led to a more intense color change

References

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Chemical Oscillators
Thank You
for your attention!!!
Team Fryganiotis

Possible errors

- It is possible a small percentage of declination in the final results from the real results
- It is also possible a declination in the measurements of the temperature values and in the analogies of a ±3%
- The use of the magnetic stirring would have as a result a better stirring of the solution