14. INVENT YOURSELF: CHEMICAL OSCILLATORS

Team Croatia
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SAINT PETERSBURG

14. INVENT YOURSELF: CHEMICAL OSCILLATORS

Example of an oscillating chemical reaction is the **Manganese-catalyzed Bromate-Malonic Acid** reaction which results in periodic **colour changes**. Investigate how **temperature** and **turbulence** affect the **velocity** of the chemical reaction, **number** of **oscillations** and **colour intensity**.

3 different temperature

with and **without** turbulation

→ **oscillation period,** total **oscillation time** and **colour intensity**

Chosen chemical oscillator

Red

Colorless

Red

Outline

Theoretical introduction

- Chemical oscillators - general theory
- Chemical equilibrium and the speed of chemical reactions
- Manganese-catalyzed Bromate-Malonic Acid reaction

Experiment

- Materials and methods
- Hypothesis

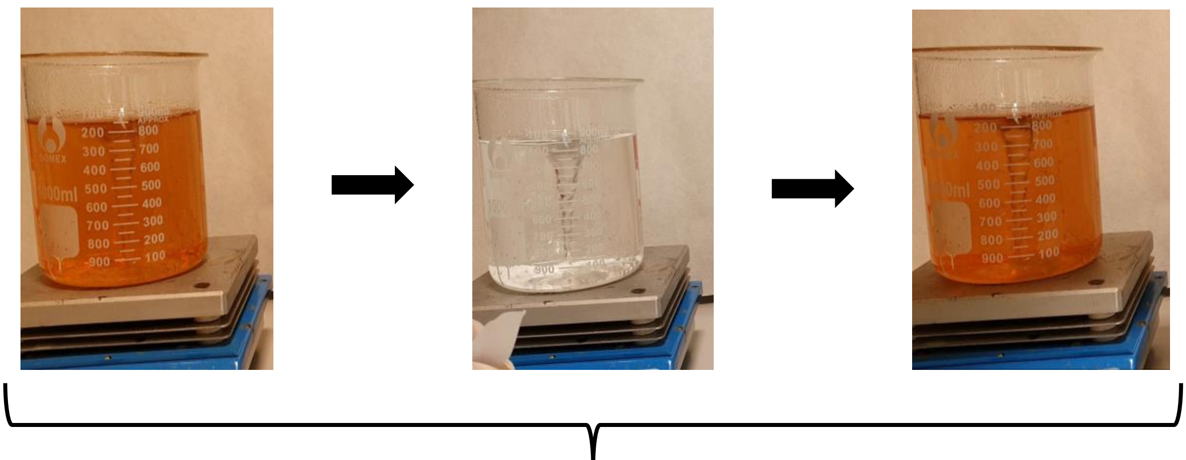
Results

- Results for various parameters

Chemical oscillators - general theory

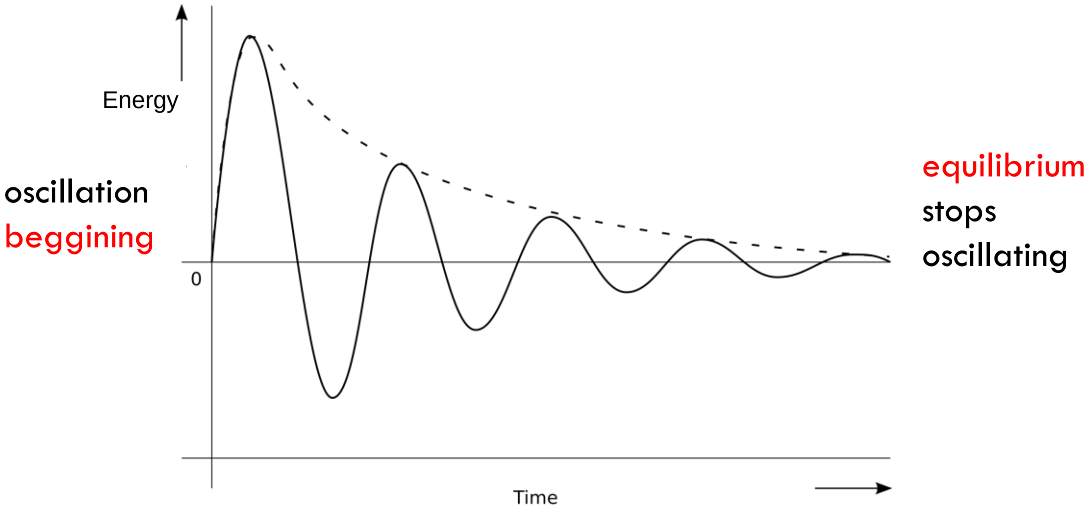
- **Chemical oscillator** – a mixture of chemicals that goes through a **periodic sequence** of **changes** (often a change of colour)

- beginning → the reaction is far from chemical equilibrium
  as the reaction oscillates → running down toward chemical equilibrium



period

Example of damped oscillator



Energy is **not restored** → **decreases** as the reaction reaches **equilibrium** → **<u>stops oscillating!</u>**

Theory | Experiment | Results

Chemical equilibrium and the velocity of chemical reactions

- Temperature **increases** → time period **decreases**

- The speed of a chemical reaction – various parameters (temperature, concentration...)

- Chemical equilibrium
  $c_{products}$, $c_{reactants}$ = const.

$$E_k = \frac{3}{2} kT$$ per molecule

Boltzmann constant
k = 1.38066x10-23 J/K

Theory | Experiment | Results

Manganese-catalyzed Bromate-Malonic Acid Reaction

0. $3CH_2(COOH)_2(aq) + 4BrO_3^-(aq) \longrightarrow 4Br^-(aq) + 9CO_2(g) + 6H_2O(l)$

1. $Br^-(aq) + BrO_3^-(aq) + 2H^+(aq) \longrightarrow HBrO_2(aq) + HBrO(aq)$
2. $BrO_3^- + HBrO_2 + 2Mn^{2+} + 3H^+ \longrightarrow 2HBrO_2 + \underline{2Mn^{3+}} + H_2O$ → Mn^{3+}
3. $4Mn^{3+} + HBrO + H^+ \longrightarrow \underline{Br^-} + H_2O + 4Mn^{2+}$ → Br^-

Red colour → **bromine**

→ **Mn^{3+} ions** → known to be **red**

Materials

Chemicals:

750 mL distilled water

75 mL concentrated sulfuric acid - $H_2SO_4(l)$

9 g propane-1,3-dioic (malonic) acid – $C_3H_4O_4(s)$

8 g potassium bromate - $KBrO_3$

1.8 g manganese (II) sulfate monohydrate, $MnSO_4.H_2O$ (s) → **catalyzer**

Materials:

1-liter beaker

magnetic stirrer (with heating)

ice

$KBrO_3$

$C_3H_4O_4$

$MnSO_4.H_2O$

Magnetic stirrer with a 1-liter beaker

Methods

1. Dilute H_2SO_4 (750 mL distilled H_2O + 75 mL H_2SO_4).

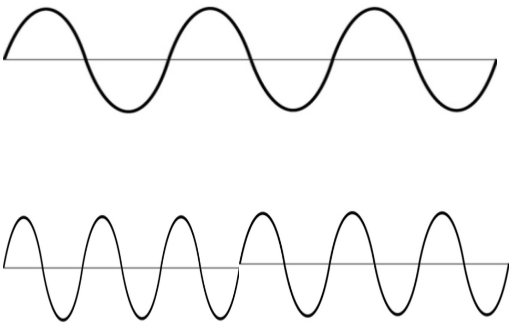
2. Place the beaker of H_2SO_4 (aq) on a magnetic stirrer.

3. Set to a specific temperature (**2.5**/ **22.5** / **42.5 °C)**, mix the solution fast enough to form a vortex and add $C_3H_4O_4$ and $KBrO_3$.

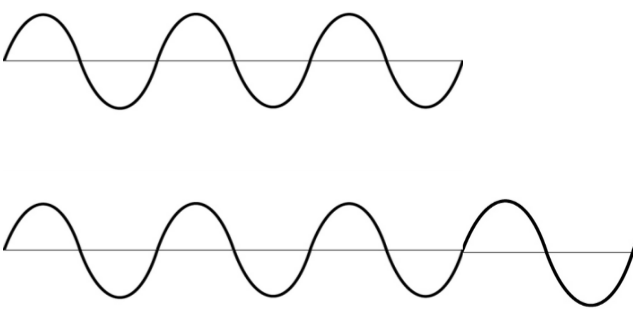
4. a) Add $MnSO_4.H_2O$ → **catalyzer**

   b) **Turn off** the magnetic stirrer and add $MnSO_4.H_2O$ → **catalyzer**

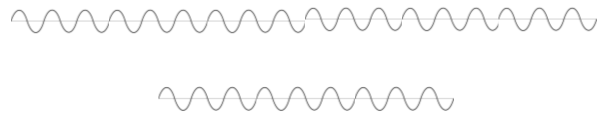
1. **Period** of oscillation



2. **Number** of oscillations



3. **Total** oscillating **time**



Hypothesis

H1: The **time period** will **decrease** with **increase** in **temperature**

H2: As the **temperature increases more oscillations** will occur

H3: As the **temperature increases** the reaction will reach **equilibrium faster**

H4: **Color intensity** will **decrease** as the reaction reaches equilibrium

H5: With **no turbulence** the reaction will proceed at a **localized** fashion

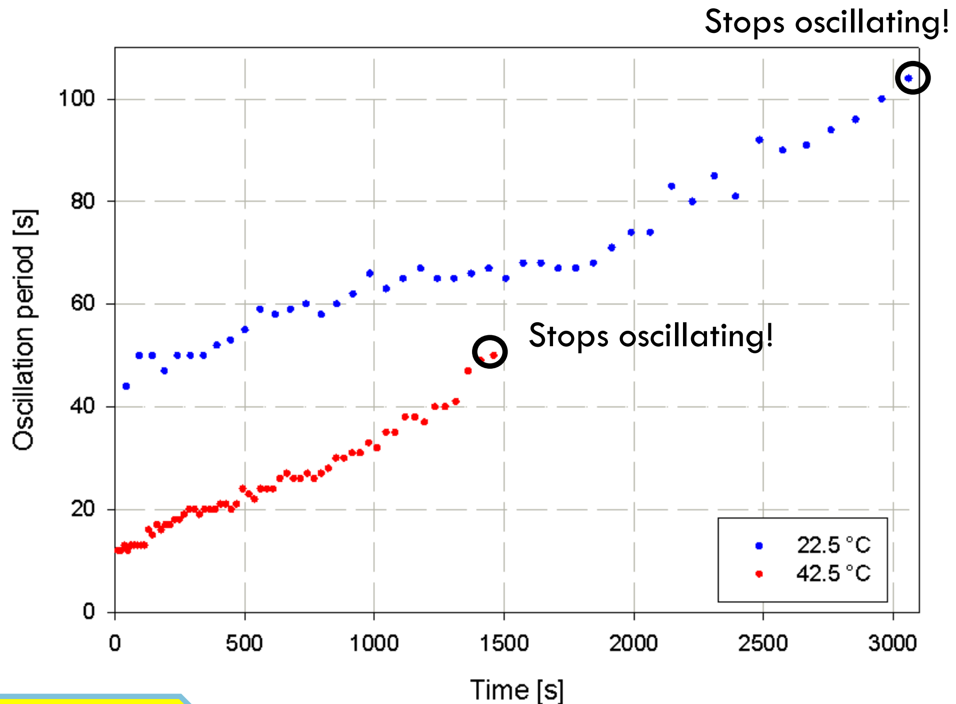
H1: The time period oscillations will decrease with increase in temperature ✓

22.5 °C:

Longest period → **104 s**

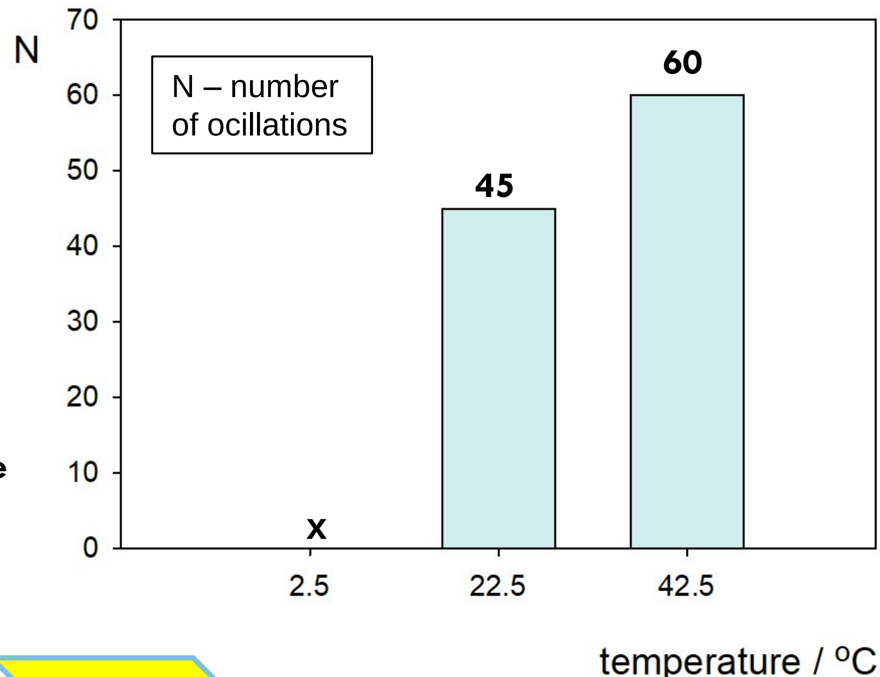
42.5 °C:

Longest period → **50 s**



Theory | Experiment | Results

H2: As the temperature increases more oscillations will occur



2.5 °C:

did not oscillate

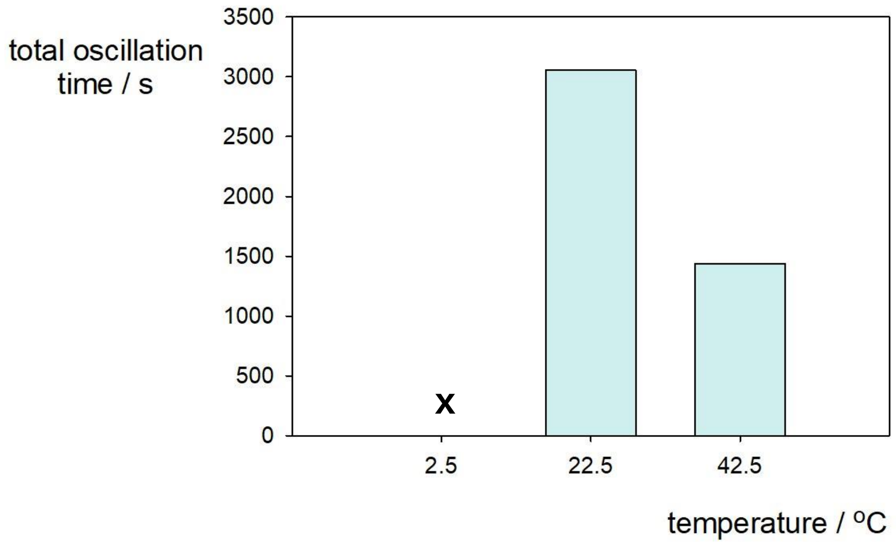
low E_k → **not enough particle collision** → **no reaction**

Theory Experiment Results

H3: As the temperature increases the reaction will reach equilibrium faster

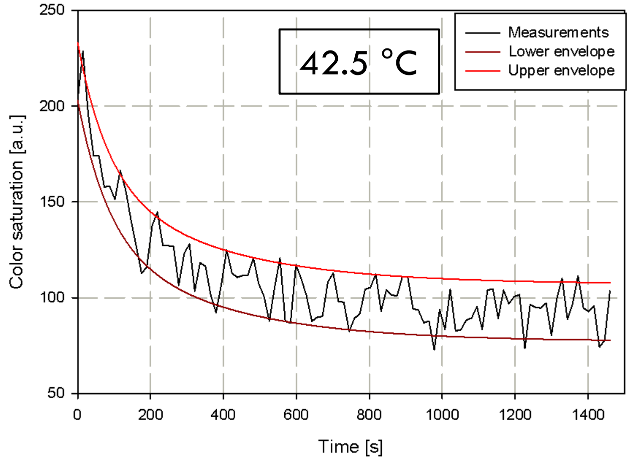
22.5 °C:
total oscillation time – **3059s**

42.5 °C:
total oscillation time – **1440s**



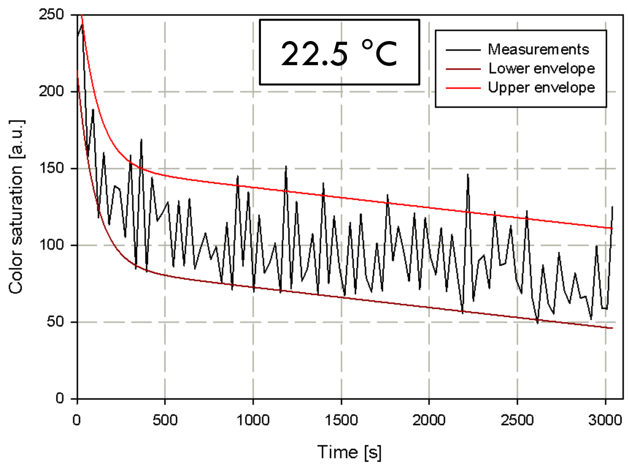
Theory Experiment Results

H4: Color intensity will decrease as the reaction reaches equilibrium ✓



42.5°C:
Δsaturation = -74

Reaction is shifted towards products → **more product → higher saturation level**

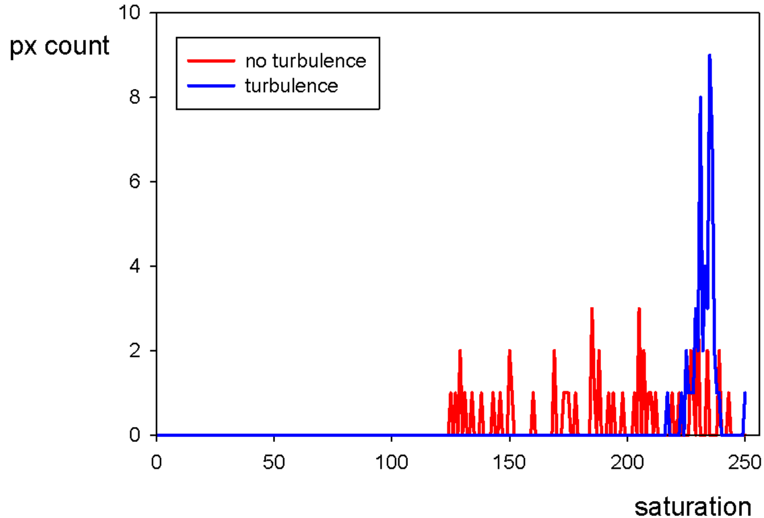


22.5°C:
Δsaturation = -92

Reaction is shifted towards reactants → **less product → lower saturation level**

H5: With no turbulence the reaction will proceed at a localized fashion ✓

no turbulence → solution is **not homogenized** → reaction happens at **different places spontaneously** → **different saturations** of red → **bigger** saturation **range**



CONCLUSION - hypotheses

- ✓ The time **period decreases** with **increase** in **temperature**
- ✓ As the **temperature increases more oscillations** occur
- ✓ As the **temperature increases** the reaction reaches **equilibrium faster**
- ✓ **Color intensity decreases** as the reaction reaches **equilibrium**
- ✓ With **no turbulence** the reaction proceeds at a **localized** fashion

OTHER CONCLUSIONS

2.5°C - <u>did not oscillate</u>

low E_k → **not enough particle collision** → **<u>no oscillation</u>**

LITERATURE

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THANK YOU!

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Additional slides – materials (mols)

Chemicals:
41.63 mol distilled water
1.4 mol concentrated sulfuric acid - $H_2SO_4(l)$
0.087 mol propane-1,3-dioic (malonic) acid – $CH_2(CO_2H)_2$ (s)
0.048 mol pottasium bromate - $KBrO_3$
0.0107 mol manganese (II) sulfate monohydrate, $MnSO_4.H_2O$ (s) ➡ catalyzer

Materials:
1-liter beaker
Magnetic stirrer (with heating)
Ice

Additional slides – all reactions

1. $Br^- + BrO_3^- + 2H^+ \longrightarrow HBrO_2 + HBrO$
2. $HBrO_2 + Br^- + H^+ \longrightarrow 2HBrO$
3. $BrO_3^- + HBrO_2 + 2Mn^{2+} + 3H^+ \longrightarrow 2HBrO_2 + \underline{2Mn^{3+}} + H_2O$
4. $2HBrO_2 \longrightarrow HBrO + BrO_3^- + H^+$
5. $4Mn^{3+} + HBrO + H^+ \longrightarrow \underline{Br^-} + H_2O + 4Mn^{2+}$

Additional slides – Oregonator model

$A = BrO_3^-$
$Y = Br^-$
$X = HBrO_2$
$P = HBrO$
$Z = Mn^{3+}$

Steps:

1. $A + Y \longrightarrow X + P$
2. $X + Y \longrightarrow 2P$
3. $A + X \longrightarrow 2X + Z$
4. $2X \longrightarrow P + A$
5. $Z \longrightarrow Y$