# Can we build reliable clocks only using chemical reactions?

## Final presentation - S4

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# A question to begin

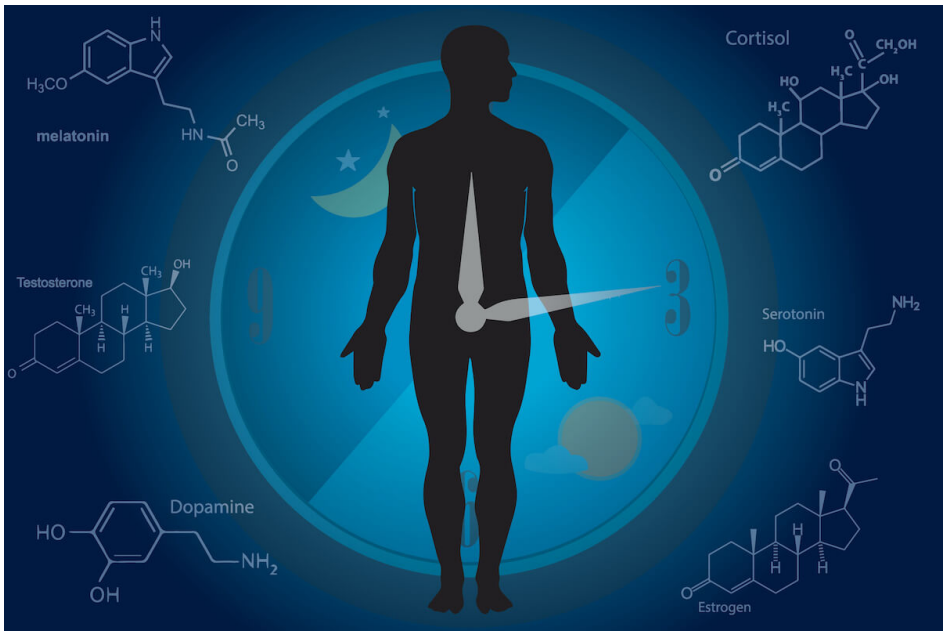
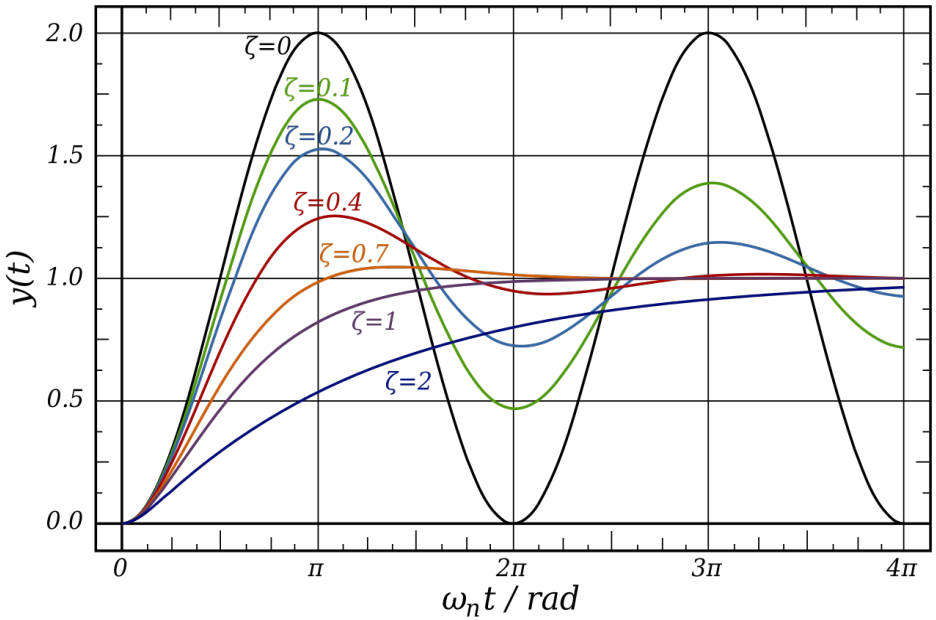



FIGURE: An illustration of the biological clock and the hormonal molecules involved - *risescience.com*.

*" Everybody has already heard talking about biological clocks. - Who has ever heard talking about* **chemical clocks***? "*

# What is an oscillation?




**A definition :**
move or fluctuation around an equilibrium position.
- Harmonic oscillations : constant over time
- Damping : decreasing over time

Figure: The effect of the damping ratio ($\zeta$) on the oscillations - *Wikimedia Commons*.

# What is an oscillation?

The equation that models the oscillations show their **periodicity/regularity**:

$$A(t) = A_0 \cos(\omega t + \phi)$$

Where $A$ represents a physical quantity, depending on $t$ the time. $A_0$, $\omega$ and $\phi$ are constants.

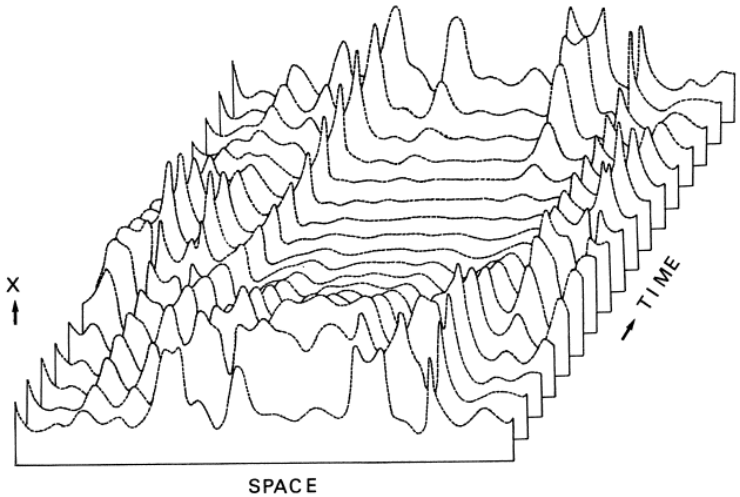



Figure: Illustration of the variations leading to chemical oscillations - *Chemical oscillations, waves, and Turbulence*. [2]

# Iodine Clocks

**The most common oscillators: with iodine**

- The *Briggs-Rauscher reaction* : iodine ($I_2$), malonic acid ($CH_2(CO_2H)_2$) and hydrogen peroxide ($H_2O_2$).
- The *Bray–Liebhafsky reaction* : more simple reaction - iodine and hydrogen peroxide only.

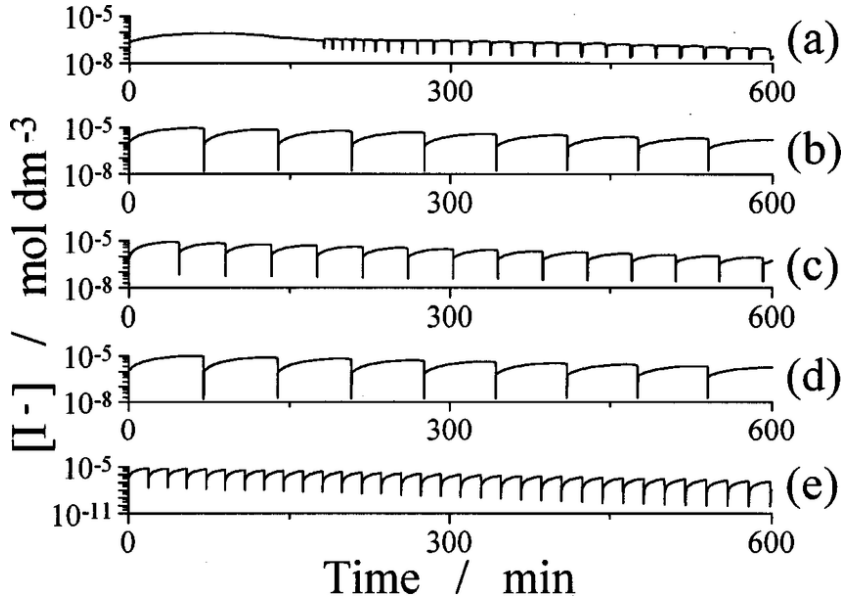



Figure: A numerical simulation of the Bray-Liebhafsky reaction's behaviour - *Journal of Chemical Physics*. [4]

# Other chemical clocks

**Candles flames** can act as an oscillator

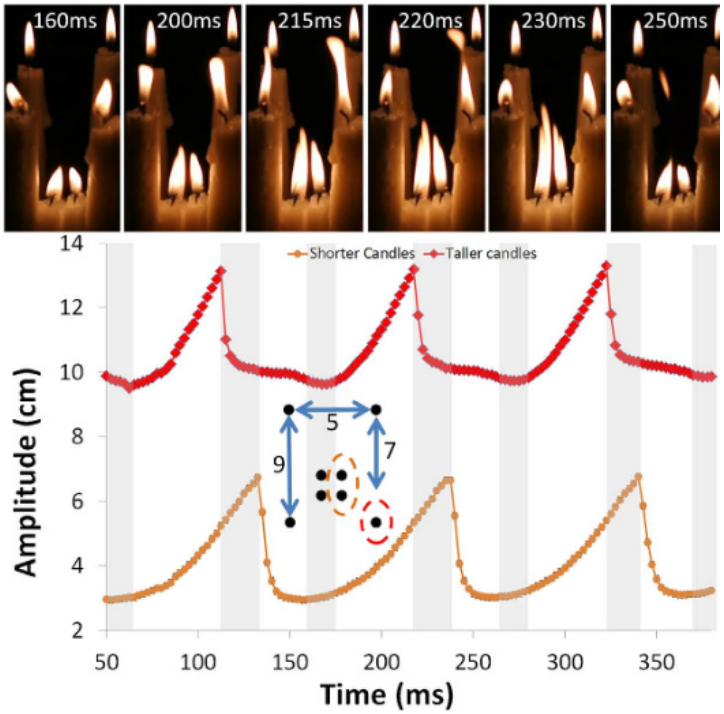



Figure: Illustration and study of candle's flames amplitude - *nature.com*. [1]

**The Belousov-Zhabotinsky Reaction**: uses bromine ($KBrO_3$) instead of iodine. Shows spatial oscillations.

Figure: Picture of the reactional media in Belousov-Zhabotinsky - *Saylor Academy*.

# Specifications for answering our question

Let's have a concrete example: **A timer to help children with teeth washing, made with visual chemical oscillating reactions**

- Duration: 2 to 3 minutes after activation
- Periodicity: at most 1 full cycle within the expected duraction
- Knowledge of the time: should be easy to understand (children)

# Elements of answer

The **traffic light reaction**: A redOx reaction, involving color indicators

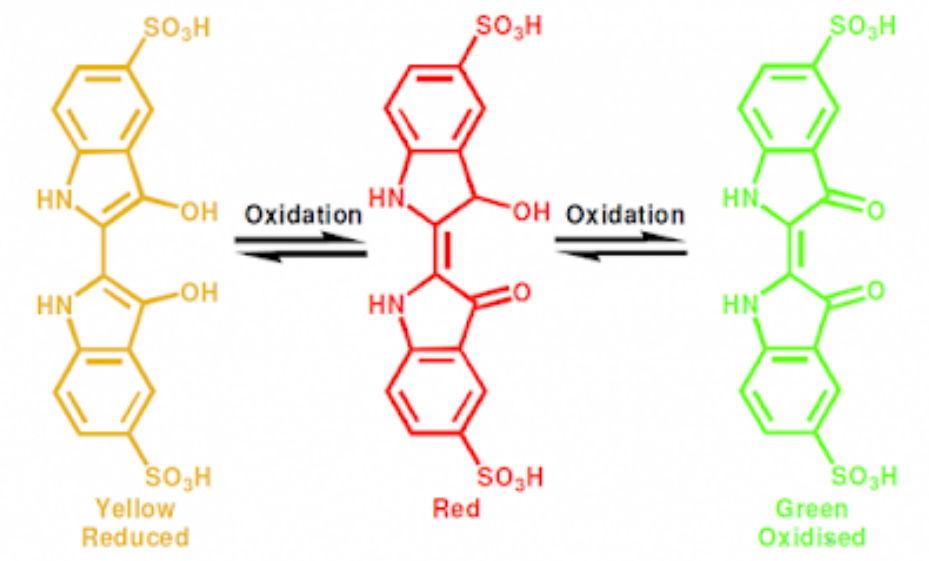



Figure: The color variations of the indigo carmine during the traffic light reaction - *According to the NCSUniversity*.

Spectroscopic study possible $\rightarrow$ determination of the right concentration of reactants $\rightarrow$ Thus the reaction can last 3 minutes

# Limitations to the chemical reactions

**The safety** ! In the traffic light experiment:
$\rightarrow$ Basis at high concentration (NaOH at $0,4$ M)
$\rightarrow$ Harmful chemicals (indigo carmine: skin allergies, ...)

**The reaction's requirements** In the traffic light experiment:
$\rightarrow$ Stirring during all the reaction
$\rightarrow$ Replacing chemicals between each experiment

# To go further

Existing **links between mathematics and oscillating reactions** cinetics

" *Chemistry is essentially a mathematical science*" - Linus Pauling (1901-1994) - Nobel prize in chemistry (1954) and peace (1962)

Assuming the reactions :

$\alpha A + \beta B \longrightarrow cC + dD \ (\star)$

$\gamma C + \varepsilon E \longrightarrow aA + dD \ (\star\star)$

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$\alpha A + \beta B + \gamma C + \delta D + \varepsilon E \longrightarrow$
$aA + bB + cC + dD + eE$

The stoichiometric coefficients matrix[3] :

$$\begin{array}{c} \\ aA \\ bB \\ cC \\ dD \\ eE \end{array} \begin{array}{c} \begin{array}{ccccc} \alpha A & \beta B & \gamma C & \delta D & \varepsilon E \end{array} \\ \begin{bmatrix} x_{\alpha a} & x_{\beta a} & x_{\gamma a} & x_{\delta a} & x_{\varepsilon a} \\ x_{\alpha b} & x_{\beta b} & x_{\gamma b} & x_{\delta b} & x_{\varepsilon b} \\ x_{\alpha c} & x_{\beta c} & x_{\gamma c} & x_{\delta c} & x_{\varepsilon c} \\ x_{\alpha d} & x_{\beta d} & x_{\gamma d} & x_{\delta d} & x_{\varepsilon d} \\ x_{\alpha e} & x_{\beta e} & x_{\gamma e} & x_{\delta e} & x_{\varepsilon e} \end{bmatrix} \end{array}$$

Linked to the reactions' speed, for example

$$v_\star = k_1[\mathrm{A}]^\alpha[\mathrm{B}]^\beta = \frac{\mathrm{d}[\mathrm{C}]}{c \times \mathrm{d}t}$$

and $v_{\star\star} = -k_2[\mathrm{A}]^a[\mathrm{D}]^d = -\dfrac{\mathrm{d}[\mathrm{E}]}{\varepsilon \times \mathrm{d}t}$

# Bibliography


[1] Kolar-Anić L. (Bellegarde University) D Čupić Z. (Bellegarde University). "Contraction of the model for the Bray–Liebhafsky oscillatory reaction by eliminating intermediate I 2 O". In: *The journal of chemical physics* (1999).

[2] Y. Kuramoto (Kyoto University). *Chemical Oscillations, Waves, and Turbulence*. Springer-Verlag, 1984.

[3] Shanks N. *Modeling biological systems: the belousov–zhabotinsky reaction*. Kluwer Academic Publishers, 2001.

[4] Forrester D. M. (Loughborough University). "Arrays of coupled chemical oscillators". In: *Openaccess nature.com scientific reports* (2015).